THE PRESERVATION OF THE CAPE FLORA

Status, Causes of Rarity, Ideals and Priorities

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A thesis presented for the degree of Doctor of Philosophy in the Faculty of Science, University of Cape Town.

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Errata: The Preservation of the Cape Flora

Chapter-page (column) line number from top (**d**) or bottom (**u**).

1-7 (1) 10d: "twice as many species **as** any island"
1-10 (2) 8u: UCT = University of Cape Town.
1-14 (2) 2d: replace "inventorization" with "**the taking of inventories**".
1-15 (1) 3d: replace "inventorization" with "**the taking of inventories**".
1-17 (1) 21u: "noda of species **richness**".
1-19 (1) 5d: PRECIS is defined in the Addendum.
1.1-13 (2) 3u: "adjacent **to** the sea"
2.1-22 (2) 21d: replace "invariable" with "**invariably**".
2.1-27 (1) reference #6: replace "Sevados" with "**Saunders**".
2.2.1-1 (abstract) 9d: replace "where" with "**were**".
2.2.1-7 (1) 4u: replace "name changes" with "**Red Data Book status** changes".
2.2.1-9 (1) 20u: replace "name changes" with "**Red Data Book status** changes".
2.2.1-9 (1) 15u: replace "name changes" with "**Red Data Book status** changes".
2.2.1-11(1) 13u: "attempts at weighting species **for setting conservation priorities**".
Table 2.2.2.1: Move footnote numbers 1-4 to the right by one column.
2.2.2-11 (2) 3d: delete ")".
3.2-14+15: Reference Pressey & Nicholls: "**A.O.**" not "O.A. Nicholls".
S-11: Reference Pressey & Nicholls: "**A.O.**" not "O.A. Nicholls".

Abstract

The Cape Floristic Region (CFR), covering 90 000 km^2, comprises one of the world's six floral kingdoms. With 8600 species, of which 68 per cent are endemic, it ranks amongst the richest of temperate and tropical floras. Although 19 per cent of the CFR occurs in nature reserves, by far the majority of the preserved area comprises Mountain Fynbos. Only 0.5 and 3 per cent of the original extent of Renoster Shrubland and Lowland Fynbos is preserved, respectively. In this study Fynbos vegetation is identified as the richest habitat for Red Data Book (RDB) plant, freshwater fish, amphibian, butterfly, and reptile species in southern Africa. The greater Cape Town metropolitan area is identified as containing by far the highest richness of RDB plant, butterfly, reptile and amphibian species in the CFR. Thus, this area ranks globally as one of the most urgent conservation priorities. The study also illustrates that previously used methods for evaluating priority conservation areas have under-rated species-poor areas containing a high proportion of RDB species. By correcting for species richness, a far more realistic picture of threatened areas can be obtained from RDB taxa. This study predicts, using a priori *hypotheses based on ecological traits, and finds, that seed dispersal and regeneration strategies are most strongly correlated with rarity, most specifically with distributional area. Using distributional data for the Proteaceae, this study estimates that 95 per cent of all vascular plant species in Fynbos can be preserved in 16 per cent of the area. It also identifies the sites that require preservation if the maximum protection of floral diversity is to be realized. Two null models for evaluating the efficiency of a spatial configuration of reserves are proposed. Utilizing an iterating selection procedure, this study explores various algorithms, based on species richness and rarity, to construct ideal reserve configurations. This study provides the first empirical confirmation that the ideal approach to designing a reserve configuration is to identify areas of high endemism and richness in distinctive vegetation types within particular biogeographical regions. Thus, this study pioneers the use of RDB data to identify priority conservation regions, provides one of the first assessments of the causes of rarity in plants and establishes useful null models and algorithms for the identification and testing of ideal reserve locations in the design of integrated reserve networks. Not only does this study contribute towards theoretical reserve selection procedures, but it provides one of the most advanced frameworks for the preservation of a top conservation priority in the world, the CFR.*

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I thank my doctoral supervisor, Prof. W. R. Siegfried, for his encouragement and the free reign to develop this thesis while pursuing other interesting sidelines, sometimes contrary to his advice. My wife, Patricia Holmes, has provided continuous support and encouragement.

In addition to those persons acknowledged in specific papers, I thank the following for useful discussion: William Bond, Richard Brooke, Richard Cowling, Amots Dafni, Craig Hilton-Taylor, Brian Huntley, June Juritz, Ian Macdonald, Eugene Moll, Shirley Pierce, John Rourke, Roy Siegfried and Brian van Wilgen.

Funding for this study was provided by the Foundation for Research Development through its Fynbos and Conservation Biology Programmes, and the University of Cape Town and the National Botanical Institute. In addition, I wish to thank my parents-in-law, Prof. and Mrs J.C. Holmes, for financial assistance to enable the completion of this study.

This thesis is presented as a series of papers, as submitted to journals and books. As a consequence, styles vary between papers and some repetition is inevitable. Specifically, nomenclature of vegetation types changed during the period under study: synonyms used in different papers are provided in section 1.1.

Disclaimer

All the papers in this thesis have benefitted from discussion with coauthors and colleagues. I, however, undertook the principal tasks of collation and analysis of the raw data on which all parts of the thesis are based, except for Paper 2.1, where Sue Tansley undertook preliminary analysis (presented in her MSc).

The compilation of the Proteaceae ecological data base was undertaken in consultation with John Rourke over three years (1983-1986).

Except as specified above, I testify that this thesis is entirely my own work.

A.G. Rebelo
Kirstenbosch, July 1991

Preamble

The Cape Floristic Region (CFR) is one of the world's six Floral Kingdoms (Takhtajan 1986). It has the richest flora of the five Mediterranean climatic regions, which generally have the richest temperate floras, and exceeds that of most tropical and island floras in terms of the proportion of endemic plant taxa (Bond & Goldblatt 1984, Table 1). Although it occupies an area of only 90 000 km^2, the CFR contains more than twice as many species (8 600) of any island of equal size (Bond & Goldblatt, loc. cit.).

Over 60 per cent of the Red-Data-Book plant species of southern Africa occur in the CFR (Hall & Veldhuis 1985), which comprises only four per cent of the subcontinent's area. Many of the larger mammal species are extinct in the CFR, or have been re-introduced from populations outside the CFR (Skead 1980) - this is often not reflected in Red Data Books for birds and mammals, as the CFR is a small proportion of the area of the subcontinent. Together with the remaining tropical rain forests, the CFR must be considered one of the world's top conservation priorities (Macdonald 1989). Fortunately, the richest element of the flora, Fynbos vegetation, is largely restricted to "nutrient-poor" soils and is well protected in the mountains (Hilton-Taylor & Le Roux 1989). However, the lowlands are considerably transformed and urgently require additional protection, most especially Fynbos and Renoster Shrubland vegetation (Boucher 1981, Jarman 1986).

South Africa has a peculiar first- and third-world mix, largely owing to its political development (Huntley *et al.* 1988). As the population of the third-world element increases, the country will undoubtedly become increasingly third-world in character and outlook. This bodes ill for the conservation programme that has developed in a largely first-world climate. Even under the most optimistic of scenarios, the rapid economic development required to uplift the quality of life of all South Africans will have to be at the expense of the environment: dams will have to be built, adequate housing provided and industrial development fostered (Huntley *et al. loc. cit.*). Rapid political strides, aimed at a just dispensation for all South Africans, irrespective of race, are in progress. Perhaps now more than ever is the time to take stock of the situation, to consolidate knowledge gained over the last few decades, and to determine priorities. Only then can we enter the turbulent future confident that we can manipulate the options available so as to minimize the transformation of our environmental heritage.

The Percy FitzPatrick Institute of African Ornithology has as its mission statement for the 1990s "to promote and undertake scientific studies involving birds, that contribute to the theory and practice affecting the maintenance of biological diversity and the sustained use of biological resources". To this end the FitzPatrick Institute has realized that much more than birds need to be studied. Thus I.A.W. Macdonald is investigating the effects of introduced alien species, a threat to which the CFR appears particularly vulnerable (Macdonald & Richardson 1986). Furthermore, before conservation options and priorities can be ascertained, the efficacy of the existing reserve network needs to be addressed: this has been undertaken for the subcontinent (Siegfried 1989), and, within the CFR, is the focus of this thesis.

This dissertation collates available information on biotic diversity relevant to conservation in the CFR and identifies some priorities and options. As such it addresses one of the most pressing and important initiatives and research needs agreed upon at the workshop of "Research Priorities for Conservation Biology" held in Florida in 1988, *viz*: "to identify areas that are critical for the protection of natural and genetic resources because of their high biotic

diversity, high levels of endemism, or because of imminent destruction of critical or unusual habitats and/or biotas" (Soule & Kohm 1989). This dissertation is, however, only a first step in this direction for the CFR.

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Table 1. The relative position of the CFR compared to the ten top "hotspot" areas in tropical forests (Myers 1988 in McNeely *et al.* 1990), ranked by number of endemic plant species.

Area	Original Extent (km^2)	Currently Untransformed (km^2)	Plant species		A/B (%)
			Total (A)	Endemics (B)	
Cape Floristic Region	90 000	60 000	8 600	5 800	68
Atlantic Forest, Brazil	1 000 000	20 000	10 000	5 000	50
W. Amazonian Uplands	100 000	35 000	20 000	5 000	25
Madagascar	62 000	10 000	6 000	4 900	82
Philippines	250 000	8 000	8 500	3 700	44
Northern Borneo	190 000	64 000	9 000	3 500	39
Eastern Himalayas	340 000	53 000	9 000	3 500	39
Western Ecuador	27 000	2 500	10 000	2 500	25
Colombian Choco	100 000	72 000	10 000	2 500	25
Peninsular Malaysia	120 000	26 000	8 500	2 400	28
New Caledonia	15 000	1 500	1 580	1 400	89

Alternative rankings by:	put the CFR in position no:
Proportion of endemic species	3
Total plant species	7
Proportion of area remaining	10

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Introduction

Rationale

A basic prerequisite of any conservation strategy is a comprehensive knowledge of the diversity of the region. Measurement of biological diversity is dependent upon the inventory and systematics of species and their distributions in space. Biogeography addresses the problems of rarity, habitat requirements and barriers to dispersal and is thus the cornerstone to any conservation strategy (Soule & Kohm 1989).

Species taxonomy in the CFR is reasonably complete for vertebrates and plants, but not for invertebrates, with the exception of butterflies. Even for plants, the taxonomy of several of the larger near-endemic families (Ericaceae, Restionaceae, Rutaceae) has not yet been completed. However, a perusal of Red Data Books rapidly reveals that even a rudimentary knowledge of the autecology of species is confined to the higher vertebrates. Thus notes are available for only 14 per cent of the Red Data Book plants in the CFR (Hall & Veldhuis 1985), the majority of which merely highlight changes in distributional status. Similarly, "Indeterminate" and "Uncertain" categories account for 49, 17, 0, 0, 6, 24 and 31 per cent of total Red Data Book plant, butterfly, fish, amphibian, reptile, bird, and mammal species in the CFR, respectively. This reflects a combination of the total number of Red Data Book species and the research effort undertaken in each taxon (Section 2.1). While some data exist on the importance of species interactions in pollination (Rebelo 1987) and seed dispersal (Bond & Slingsby 1983, Knight 1987), keystone or mobile link species have not been identified, if indeed they exist in the CFR.

A further problem is that of the scales used for recording biological information. In southern Africa, species' distributional data are routinely mapped at the quarter-degree grid scale (Edwards & Leister 1971), with units measuring *ca* 24 X 27 km^2 in the CFR. This applies to plants (PRECIS: Gibbs Russell & Gonzalves 1984; Red Data Book: Hall & Veldhuis 1985), birds (Cape Bird Atlas: Hockey *et al.* 1989) and vertebrates (Boshoff *et al.* 1978). However, the CFR consists of a network of mountain *vs* plain topographies, and nutrient-poor *vs* nutrient-rich soils: for example, the Langeberg and Swartberg Mountains, which transverse the southern portion of the CFR, are, on average, about 7 and 15 km-wide respectively, separated by a 50 km wide plain containing montane-islands of various dimensions. A quarter-degree grid system is thus too coarse for describing the spatial scale of phytogeographical heterogeneity in the CFR (Section 3.1). Unfortunately, partly because of the use of the standardized grid scale, and partly because of the high species richness and high relief, data are too scarce for use at very much finer scales. To date this has only been attempted, at an eighth-degree grid scale (12 X 13 km^2), for the Proteaceae (Appendix 3).

A superior system would be to map distributional data to spot localities, so that distributions could be determined independently of a raster (grid) system. Geographic Information Systems (GIS) technology offers such an opportunity (Scott *et al.* 1987). Unfortunately, GIS has only recently (July 1990) been updated at UCT, and will probably not be of much use to conservation planning for several years yet. The winter-rainfall region of South Africa is particularly fortunate in that climatic (cold units, evaporation, max-min temperatures, radiation, rainfall, sunshine, and wind), landform (altitude, aspect, gradient and slope), pedological (all

physical features, clay content, colour, compaction levels, crop suitability, depth limiting factors, diagnostic horizons, drainage, effective depth, erosion, lime status, locality, moisture content, natural effective depth, nutrient content, pH, resistance, salinity, sand content, soil type, stone occurrence and underlying material) and plant cover data at one second grid and minute resolutions are available for GIS applications from the Department of Agriculture and Water Supply (Macdonald & Pressinger 1989). A possible application to conservation using this data is outlined below: it requires, however, that the GIS technology at the University of Cape Town be firmly established.

In this dissertation I have used the most appropriate data bases to ascertain what is preserved and to address the conservation options and priorities in the CFR. There is no central thesis.

The dissertation started out as a three-year project to evaluate the proposed system of nature reserves in the lowlands of the CFR. It soon became clear that Lowland and Mountain Fynbos were not the distinct entities they had previously been assumed to be, at least on structural grounds (Cowling *et al.* 1988, Rebelo *et al.* 1991).

Furthermore, analyses of published and unpublished data for investigating the relationship between area and species richness within the principal vegetation types of the CFR soon got snagged on "manifold taxonomic problems" (Campbell 1985a). Furthermore, GIS technology, while present in the Surveying Department at UCT, was unsupported and relatively unexplored. Both these problems have been resolved recently.

A survey of the corridors available for preservation of Fynbos along the N7 National Road, and the impact of mowing was investigated (in prep.) as part of the project, but are not included in this dissertation. In addition, a structural analysis of the vegetation of the Riversdale Flats (Rebelo *et al.* 1991) and the conservation implications (Cowling *et al.* 1990) are not included herein.

Rather this dissertation incorporates only those papers which I found most stimulating. Theses explored during their production include (sections addressing specific theses are parenthesized):

A reserve network can be designed so that a Minimum Viable Population of all target species is not required for any specific reserve provided that corridors are available (1.1).

Any management programme based on single species preservation will be to the detriment of many other threatened species. Management programmes aimed at preserving biotic diversity should be geared to maintaining natural ecosystem processes (1.1, 2.1).

Rarity is determined largely by short dispersal distances and low persistence. Many of the theoretical correlates of small population sizes (loss of heterozygosity, inbreeding depression, stochastic and demographic instability) do not operate to make species rare, but only operate once species have become rare (2.2).

A reserve network based on the interpretation of (even a rudimentary knowledge of) biogeographic zones, vegetation types or turnover rates (delta diversity) will preserve a considerable proportion of the biotic diversity, provided that preservation and priorities are emphasized in centres with high endemism and species richness (3.1, 3.2).

Criteria used to assess wildlife conservation potential must be analyzed for correlations among variables if an objective ranking is desired (3.3).

Not all these theses have been addressed to my satisfaction. It is my wish to address them further in the future.

A review of available data bases

An assessment of the conservation status of the CFR can be undertaken at various hierarchical levels. The most useful of these are: species, plant assemblages, vegetation types, and biogeographical zones.

Species

The use of species as units of biological diversity offers the most applications. Species are important determinants of plant assemblages, vegetation types and biogeographic zones, so that data for each of these disciplines can be resolved from species analysis.

However, species may not be the appropriate unit for preserving biotic diversity (Bond 1989). Thus species belonging to a monotypic family might be "valued" as higher than one belonging to a monotypic genus, and a species of *Erica*, with 860 congeners might be considered to have a still lower status (Ferrar 1989). Similarly, species with significant inter-populational variation, might be considered to comprise many units, compared to a uniform species of limited distribution (Bond 1989) - presumably a species with little geographical variation but high intra-population variation would fall between the two. Thus Bond (*loc. cit.*) concludes that species richness in a clade may be the result of the fickleness of isolation mechanisms and may have little ecological, economic, genetic or conservation value.

However, it can be argued that all speciation is the result of historical accident, be it continental drift, a chance distribution event or capricious female choice. The unit in ecology, evolution and genetics is the individual in its population. Inter- and intra-population variability are the result of gene flow over distance and the local persistence of populations: critical components determining the conservation options available for any species (Ledig 1986, Templeton 1986). Furthermore, differences in variation are readily incorporated into the binomial concept as subspecies, varieties and forms, and the "evolutionary" species concept (a lineage sharing a common evolutionary fate) accommodates this variation, although it may not be appropriate for all purposes (Templeton 1986). That these rankings vary somewhat among taxonomists, who can be broadly classified as "splitters" and "lumpers", is probably as much a reflection of the complexities of species as the lack of sufficient taxonomists to assess critically the "hypotheses" proposed by their colleagues. Lastly, the unit for conservation remains ultimately at a species level: sufficient minimum viable populations must be preserved to prevent stochastic extinction (Gilpen & Soule 1986). Communities and ecosystems depauperate in species providing some commodity required by other species will collapse to a new equilibrium if these mobile-link and keystone species become extinct. Even at the community and ecosystem level, critical components are populations comprising the species (Pimm 1986).

I am unconvinced by most of the arguments put forward to date as to why we should conserve biotic diversity, including species richness (*e.g.* McNeely *et al.* 1990). The tropical ecosystems are relatively diverse, despite catastrophic events such as that of about 60 million years ago (Alvarez & Asaro 1990). Although only a few taxa survived these extinctions, which apparently occurred rapidly even by human standards (Alvarez & Asaro *loc. cit.*), diversity and species richness was apparently restored, despite the taxonomic biases in survival. No-one has yet decried the loss of species which probably

occurred as a direct result of Pleistocene glaciers occupying much of the northern hemisphere, nor has anyone proclaimed the depauperate communities which have replaced the glaciers as non-resilient or "unstable". The greenhouse effect can probably be adjusted one way or the other, irrespective of the preservation status of tropical forests. New medicines are as likely to be found by tinkering in the laboratory and studying human biochemistry, as by randomly cataloguing the myriads of compounds in the many as yet unstudied plant species or populations.

A common thread runs through all these arguments, however: we cannot predict what the future will bring. The destruction of the biotic diversity on earth will probably decrease our available options in an unknown and uncertain future. Ecologically, economically, medically and aesthetically, the more we preserve, the greater our ability to adapt to future changes. If conservation biology has a lesson to teach it is this: the method of preserving all types as one pair (presumably the additional six pairs of ritually clean types and birds were used as provisions) within a vessel of 38 000 m^3 will not work again - this is no 40-day crisis. Nor can we afford to wait the millions of years apparently required for species radiation to restore biotic diversity - we currently do not have the technology or theory to create or recreate biotic diversity. We might never need the quagga, the dodo or the passenger pigeon. But one thing is certain - should we at some time in the future have a need for them, they are no more useful to mankind than are *Archeopterix*, *Tyrannosaurus* or the Unicorn.

Our aim should be to preserve as many species as possible: those which are more variable or contain significant variation among populations should be preserved independently in as many types as possible. The species concept may not have been designed for preservation; it may be inadequate to cope with the diversity of life on earth and the rapidity with which species are becoming extinct, but it is the only concept currently available. I agree with Bond (1989) that we must not allow inventorization to interfere with exploring "the consequences of fragmentation and degradation of habitats, the invasion of alien species, and the many subtle and insidious effects of people and industry on the survival of our biota". However, I fail to see how we can investigate any of these phenomena without resorting to the use of the species concept, with emphasis on the use of species richness which Bond decries.

Lists of species present in nature reserves have been compiled for threatened fauna and flora under the South African National Plan for Nature Conservation (Macdonald & Pressinger 1989) and by the FitzPatrick Institute (Siegfried 1989). "Complete" lists are available for between 9 and 25 per cent (with plants being the worst and birds the best documented taxa) of the 582 statutory reserves in South Africa. Partial lists bring the totals to 26 and 40 per cent, as the worst and best documented taxa (amphibians and mammals), respectively (Siegfried 1989). Published comprehensive suites of complete check lists of species for all five major taxa (plants, amphibians, reptiles, birds, and mammals) were only available for one per cent of reserves in South Africa (Siegfried 1989). This is clearly an inadequate data base to assess preservation of species in the CFR. Nevertheless, it is probably true to state that almost all (>95%) extant bird, non-flying mammal, and (>90%) reptile and amphibian species in the CFR occur in statutory nature reserves (Siegfried 1989). Data for plant species are not available, but for Mountain Fynbos are estimated at around 93 per cent, based on the Proteaceae (Section 3.1).

Undoubtedly, the largest available data bases for assessing the conservation efficacy of the existing reserve network for plants are the local herbaria (Bolus, Compton and Stellenbosch) and the National Herbarium in Pretoria. The vast majority of herbarium records from this century contain detailed locality data suitable for resolution to a few minutes (2-3 km) or less.

However, since the data in local herbaria are not computerized, they are of limited use: their inventorization should be regarded as a matter of urgency (Addendum 1). Herbarium records in the National Herbarium are computerized, including detailed locality coordinates (Gibbs Russell & Gonsalves 1984), but are plagued by distributional and identification problems: these errors may comprise 26 per cent in terms of species per magisterial district (Addendum 1). Such problems are perhaps to be expected of a herbarium far removed from the expertise required to identify a complex flora: the problems are receiving attention (B.J. Huntley pers. comm.). These data would be most useful if data bases from the four herbaria were integrated and made compatible with GIS technology (Addendum 1).

A summary of the information present in the four herbaria and recent revisions exists in the form of a catalogue of species in the CFR (Bond & Goldblatt 1984). The flora totals some 8 594 species (including 16 *Erica* species unintentionally omitted), but unfortunately distribution ranges are only resolved to magisterial districts. These are useless for conservation purposes: biogeographic zones would have been far more appropriate. It appears that the catalogue may have a six per cent error based on species per magisterial district, in large part owing to new localities extending species distributions (Addendum 1).

An additional source of species data is the many studies of vegetation communities, undertaken throughout the CFR. By 1980, some 122 localities had been studied (Boucher & McDonald 1982). Collating the species lists of these studies is problematical since taxonomical re-appraisals have resulted in a high proportion of synonyms. This problem has been addressed recently and software is available to convert synonyms to current species names (Boucher 1990). Other problems complicating comparisons between regions include: different quadrat sizes used; the sub-sampling procedure of releves only capturing a proportion of the total species richness of a study area; variable size of study areas; and, the exclusion of "rare" and "infrequent" species from published results. Furthermore, the high species richness effectively limits the numerical analyses that can be undertaken on existing hardware. Nevertheless, these data are currently the focus for studies on species turnover and endemism in the CFR (Boucher 1988, Cowling *et al.* 1989, Cowling *et al.* MS, Linder MS).

By far the most exciting avenue for research available to date can be undertaken on C. Boucher's (1988) semi-detailed survey of the vegetation (Thicket, Renoster Shrubland and Fynbos) of the western Cape lowlands. These data conform to the gradsect sampling technique (Austin & Heylingers 1989) and are thus amenable to Generalized Linear Modelling (GLIM) (Nicholls 1989). Coupled with the Department of Agriculture and Water Supply's winter-rainfall region data base (Macdonald & Pressinger 1989), the historical distribution of species in Renoster Shrubland, long since converted to wheat fields, can be reconstructed. This should cast some light on the currently intractable problem of why Renoster Shrubland has relatively few Red Data Book species. Did the species become extinct before botanical collecting began, as suggested by Hall and Veldhuis (1985)? Or was Renoster Shrubland formerly a grassland, as suggested by Skead (1980), with very few localized endemics?

The advantage of the data base, however, is that by using GIS technology on the GLIM equations for determinants of species distributions, the distribution of species can be tracked under various different regional conditions of temperature and rainfall. Furthermore, the influence of possible corridors and degrees of fragmentation can be modelled and climate-driven extinctions predicted. These insights will allow the efficient planning of the conservation, as opposed to the preservation, of the vegetation within the lowlands of the CFR in terms of possible global warming scenarios. In the current economic and political

environment, however, it appears that any such conservation plan will never be realized. Although both Dr C. Boucher and Prof J. Juritz are keen to undertake analyses, the lack of suitable GIS technology at UCT has resulted in analyses temporarily being shelved.

An important additional data source, especially for determining priorities in terms of species and areas requiring preservation, are the Red Data Books. A Red Data Book for plants is available for the CFR. Red Data Books for mammals, birds, reptiles, amphibians, fish and butterflies are available for South Africa (Ferrar 1989). Fortunately, with the exception of birds and mammals, a low proportion of Red Data Book species are shared between the CFR and the rest of South Africa (Section 2.1). Unfortunately, the recording of distribution ranges has not been standardized among the Red Data Books: thus plants are recorded by quarter-degree coordinates for herbarium records; reptiles/amphibians by maps of quarter-degree grid-squares with historical and current distributions identified; birds, fish and butterflies by maps with dots signifying museum and/or sight localities (at different map scales and data resolutions); and, mammals by shaded maps of the general area in which extant populations probably occur. Consequently, comparative data can only be resolved to the scale of a quarter-degree grid square.

A synthesis of threats, concordances in noda of richness among threatened taxa, priority areas for preservation, and susceptibility among taxa to threats is presented in Section 2.1.

Since the available data bases outlined above do not meet the resolution required to determine patterns of endemicity and species richness at the scale of pattern in the CFR, data had to be obtained at a finer resolution than quarter-degree grid scale. Ideally such studies should emphasize taxa which are better known and which parallel biogeographic patterns in less amenable taxa (Soule & Kohm 1989). To this end, I extracted distributional data for the species of Proteaceae in the CFR from reviews and herbarium specimens at an eighth-degree scale (Section 3).

The limitations of these data must be appreciated. Most importantly the species of Proteaceae are largely confined to Fynbos vegetation and its ecotones. Consequently analyses do not contribute to the preservation of Afromontane Forest, which is well preserved (Siegfried 1989), or Thicket and Renoster Shrubland vegetation, which have been impacted by human activity to a far greater degree than Fynbos (Jarman 1986). Fortuitously, by far the majority of extant species in the CFR, including a very large proportion of the endemic species, are confined largely to Fynbos vegetation (Bond & Goldblatt 1984). Furthermore, the distributional data cannot be regarded as comprehensive, although this is mainly a problem with the more common species, especially those confined to high altitudes. Distributional data are particularly lacking in the larger Proteaceae, owing to their large inflorescences which require considerable space in herbaria (Rebelo *et al.* 1986).

There is a need for a rapid and simple method of determining a reserve configuration which preserves the majority of species in a minimum area, especially in tropical areas where destruction is rapid and botanical surveys are inadequate. The distributional data for the Proteaceae, assuming that a grid square could be equated with a reserve, was used to determine a reserve configuration which preserves all the species at least once. Analyses were done entirely by hand, by compiling species lists for grid squares along five linked transects through areas of high species richness. Reserves were assigned to grid squares with high numbers of unpreserved species. Trial and error showed that reserves were best assigned to grid squares along the transect when preserved species fell to about 50 per cent of the total (Section 3.1). Intuitively this procedure should be efficient at ensuring that all species

are preserved within a minimum area configuration. However, this required testing.

Using an iterative approach (Pressey & Nicholls 1989a,b), I tested various algorithms to determine which resulted in the most efficient reserve configuration, in terms of the total number of reserves (= grid squares) required to preserve all the species in a specified number of reserves (Section 3.2). Of the algorithms investigated, only two proved useful: grid squares were valued either by the number of unpreserved species present or by the sum of the scarcity values of species present [where the scarcity value equalled the total number of grid squares in the region divided by the number of unreserved grid squares occupied by the species; when a species was adequately preserved, the scarcity value was set to 0]. These optimal configurations were then used to evaluate previous prescriptions for the preservation of Fynbos vegetation (including Section 3.1) and the existing reserve configuration against a reserve network assigned at random.

As Red Data Books provide data which allow the designation of "hot spots", or noda of species, considerable conservation effort should be directed towards these noda. However, a concern arose during an *ad hoc* workshop held in 1986 to determine the rarity status of all taxa of CFR Proteaceae (Tansley 1988), namely that threatened areas with few Proteaceae species might be overlooked. This problem appears universal: given a geographically-constant threat, areas containing more species are more likely to have Red Data Book species. It seemed obvious that only by correcting for total species richness could the threat to an area be correctly evaluated. I was also curious to know how correcting for total species richness would affect the distribution pattern of naturally rare species: specifically, which areas with many rare species are not correlated with areas of many common (non-rare) species (Section 3.3). However, more data on the factors affecting the distribution of naturally rare taxa are required before any theoretical inferences can be drawn from the results presented.

Using the same data base, together with ecological data extracted from the literature and estimates, I investigated the correlates of rarity in the Proteaceae (Section 2.2). I outlined all my preliminary hypotheses before commencing analysis, and then approached William Bond as a sounding board for evaluating these hypotheses, before commencing with statistical analysis. This *a priori* approach proved far more stimulating than simple analysis of the data could ever have been.

Plant assemblages

The concept of preserving plant communities is often advocated in the literature (Burgmann 1988). These assemblages reflect a combination of habitat heterogeneity and the historical availability of species. However, any site is unique in terms of its species composition and cover abundance. The *a posteriori* approach of synthesizing a classification from empirical data (Campbell 1985a) does not recognize the limits of resolution: assemblages can be refined until they equal the number of sites. It is thus absurd to suggest that all "suites of species" should be preserved (cf Burgmann 1988). Furthermore, it is not known to what extent specific communities are merely by-products of the current climate. Even small changes in climate or perturbation regime might alter communities extensively.

The many studies of vegetation communities undertaken throughout the CFR (Boucher & McDonald 1982) do not provide adequate and representative cover of the region and a synthesis is hampered by the lack of an overall vegetation typology for the region (Campbell 1985a).

Although Marloth produced the first Fynbos vegetation typology in 1908, by 1978 only six subdivisions of Mountain Fynbos had been recognized. This is not a function of the lack of heterogeneity: Fynbos vegetation varies from

0.15 m to over 5.0 m tall, in cover from 25 to 100 per cent and includes types dominated by ericoid shrubs, broad-leaf trees and graminoids (Campbell 1985a). Rather it is a function of 'manifold taxonomic problems', and the high geographic turnover (delta diversity). Thus sites which are structurally and environmentally very similar can differ floristically, with up to 15 per cent of differential species proving impossible to identify (Bond 1981, Campbell 1985a). A concept of replacement guilds has been proposed to overcome the high delta diversity, but the assignment of guilds to encompass the replacement of species reflecting similar habitats in geographically separated areas is fraught with difficulties (Cowling & Holmes MS). Campbell (1985a) discussed some of these problems, outlined alternative approaches to classifying assemblages and concluded that an *a posteriori*, structural approach (using species-bound characters where detailed structural characters were not known or understood) was the best option in Fynbos vegetation. A major limitation of the structural approach is that it is only valid for mature seral stages: thus a fair proportion of the area of any region may be too young for analyses (Campbell 1985a,b).

Only three studies utilizing a structural classification of the vegetation have been undertaken: for the Mountains (Campbell 1985b), the Agulhas Plain (Cowling *et al.* 1988) and the Riversdale Plain (Rebelo *et al.* 1991). Campbell's localities are too sparse to be of use in determining conservation options. Of interest though is the concordance between his seven mountain regions and the phytogeographical centres obtained by Weimarck (1941), using floristic data.

The two studies from the south coast plain of the CFR show potential for determining priorities for the preservation in the region using structural types: in fact, they are the most comprehensive data bases available for conservation planning in the entire south coast region. Unfortunately, about one-third of the region has not yet been surveyed. Since the data collection would involve, based on the previous studies, between 10 and 15 botanists in the field for one week, this survey should be considered a matter of urgency (Cowling *et al.* 1990).

Vegetation types

The only comprehensive mapping of the vegetation of South Africa is Acocks' Veld Types of South Africa, completed in 1952, which identifies units of vegetation with the same farming potentialities (Acocks 1975). Since these are the units historically employed to assess the conservation status of vegetation types in South Africa, data are summarized for Acocks' types in this study for comparative purposes (Section 1.1).

However, a more recent categorization of vegetation types is available for the CFR. This categorization recognizes three Mountain, two Grassy and three Lowland Fynbos types, in addition to four Renoster Shrubland, and two Thicket (=Strandveld) types within the Cape Floral Kingdom and four types (within Thicket, Forest and Karoo) categorized under the Palaeotropic Floral Kingdom (Moll *et al.* 1984, Moll & Bossi 1984). This categorization is the basis for the analysis of conservation priorities in the lowlands region of the CFR (Jarman 1986), and is the current unit for statistics on degree of alien invasion and agricultural transformation (Macdonald *et al.* 1982). The conservation status of the CFR within these vegetation types is reported in Section 1.1.

However, the three Mountain Fynbos types are not geographically segregated, being determined by aspect and moisture availability, and are not consistently applied - for example, Moll *et al.* (1984) categorized the northern Cedarberg as Dry Mountain Fynbos, whereas Moll & Bossi (1984) classified it as Mesic Mountain Fynbos. Thus the Mountain Fynbos types have not been applied in conservation studies in the region, despite their apparent consistency with Campbell's (1985b) structural classification.

Biogeographical zones

The earliest biogeographical analysis in the CFR was undertaken by Weimarck (1941), using plant distributions to delimit "phytogeographical" centres and subcentres. Oliver *et al.* (1983) used the PRECIS data base, analyzing species in the major Fynbos plant families, on a quarter-degree grid square scale, to determine patterns of species richness and centres of endemism. Although only preliminary (*viz.* subgroups and hierarchies were not investigated), these results confirmed Weimarck's regions, with the exception of the south coast, which Weimarck included with the Langeberg Mountains rather than with the Agulhas plain. Using structural data, Campbell (1985b) resolved a pattern for the mountains similar to that of Weimarck.

Using the Proteaceae distributional data, phytogeographical zones were determined for the CFR using TWINSPAN and DECORANA (Rebelo & Rourke, in prep). These were used to determine the efficacy of the existing reserve network (Section 1.1), and the dispersion of ideal reserve networks relative to centres of endemism (Section 3.1).

Unfortunately, insufficient data are currently available to ascertain centres of endemicity for Renoster Shrubland and Thicket vegetation.

Hall and Veldhuis (1985) presented summary maps of Red Data Book plant species using a combination of vegetation types, biogeographic zones and apparently arbitrary subdivisions. Although their methodology was not stated, perusal of the Proteaceae data suggest that the maps were constructed, in part, from data at the quarter-degree grid scale: the resolution reported in the maps is thus not warranted by the data. By amalgamating their regions, I hope to have overcome this difficulty in comparing the distribution of Red Data Book taxa between biogeographical zones (Section 2.1). A major problem is that for such an analysis to accurately reflect the intensity of threats and their impact, regional Red Data Books which include species threatened within a region, irrespective of their status outside the region, are required (Section 3.3).

Conclusion

Despite a plethora of species inventories at a variety of scales, it is not possible to evaluate the conservation status of the CFR on a species basis. Although the existing reserve system can be evaluated in terms of broad vegetation types and biogeographical regions within the CFR, there are insufficient data to explore the conservation implications of species turnover and endemicity for the entire region in detail. Nevertheless, given the attention the region deserves, these deficiencies can easily be corrected. Furthermore, the region is far better known than many tropical forests and can therefore be used as a model for testing general principles so that conservation action based on available data can be applied in the tropics.

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Part 1. Status

1.1

Preservation of biotic diversity in the Cape Floristic Region: a historical and theoretical appraisal of the existing reserve network.

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Chapter 13. Oxford University Press, Cape Town.

PRESERVATION OF BIOTIC DIVERSITY IN THE CAPE FLORISTIC REGION:

A HISTORICAL AND THEORETICAL APPRAISAL OF THE EXISTING RESERVE NETWORK.

A G Rebelo

The Cape Floristic Region (Figure 1.1.1) is an area of pronounced plant species richness and endemism (Bond and Goldblatt 1984, Cowling et al MS). The region includes more than 8550 species of which about 68 per cent are endemic. The region includes five, largely unrelated vegetation types, namely fynbos, renoster shrubland, thicket, karroid shrubland, and afromontane forest. These are described in Cowling and Holmes (MS).

The Cape Floristic Region has been, and is being, extensively transformed by pastoral, agricultural and urban development (Deacon and Siegfried MS), and alien plant encroachment (Richardson et al MS). This alteration is most evident in renoster shrubland and lowland fynbos, and least in mountain fynbos (Moll and Bossi 1984, Jarman 1986). In the lowlands of the western Cape only 6 per cent of renoster shrubland and 14 per cent of fynbos are currently untransformed (Boucher 1981a).

The majority of species of larger (>50kg) mammals and birds, most especially the carnivores and scavengers, were exterminated during the 1800's (Skead 1980, Brooke 1984, Smithers 1986, Rookmaaker 1989), but no regional Red Data Book, other than that for plants (Hall and Veldhuis 1985), exists. The 1320 Red Data Book plant species for the Cape Floristic Region (excluding karroid shrubland) comprise 56 per cent of the southern African total, although the Cape Floristic Region comprises less than four per cent of the total area (Hall et al 1980, Hall and Veldhuis 1985).

This situation compares with those of the most beleaguered regions of the world (Hall 1987a). However, a framework of preserved areas exists and an efficient conservation strategy could be implemented using remaining untransformed areas, although rapid urban growth and alien plant encroachment is rapidly reducing viable options.

In this chapter I provide an overview of the preservation of biotic diveristy in the Cape Floristic Region. I begin by summarizing what is currently preserved. I compare this to the optimal reserve configuration, based on preserving maximum plant species diversity in a minimal area of fynbos, in order to outline the deficiencies in the existing reserve network. However, conservation priorities must also focus on unique areas most threatened by imminent transformation. Areas containing the most Red Data Book species and extensively transformed vegetation types are obvious candidates for high priority conservation measures. Having established the priorities and location of reserves, I investigate arguments for reserve sizes, using island biogeographic and minimum viable population size principles, primarily in response to Kruger's (1977) assertion that the minimum reserve size in fynbos vegetation in the Cape Floristic Region is 10 000 ha. I end with a short speculation on preservation of alien species, human use and global climatic change.

HISTORY AND STATUS OF PRESERVATION IN THE CAPE FLORISTIC REGION

Background

Although the South African nature-reserve system did not develop according to any preconceived strategy for maximizing the preservation of biological diversity (Siegfried 1989), conservation strategies in the Cape Floristic Region have emphasized the preservation of plant species richness (Kruger 1977, Bond et al 1988). This has three origins. Firstly, the large mammal and large bird species, which form the focus of species-orientated preservation programmes elsewhere in southern Africa, were exterminated in the Cape Floristic Region long before current conservation movements came into being (Skead 1980, Rookmaaker 1989). Secondly, the high plant species richness and endemism of the Cape Floristic Region (Cowling et al MS), far outshadows that of any vertebrate taxon. Although the invertebrate fauna is probably as diverse as the flora (Rebelo 1987a), with the exception of butterflies little is known about richness in these taxa. Thirdly, by far the largest area preserved in the Cape Floristic Region was proclaimed in order to protect mountain water catchment areas (Greyling and Huntley 1984, Grove 1987), which fortuitously coincided with areas of high plant species richness.

The preservation of species richness is probably appropriate for fynbos, although the establishment and management of some large reserves in fynbos has been based largely on single species (eg Cedarberg Wilderness Area based on the Clanwilliam Cedar *Widdringtonia cedarbergensis* (Manders 1986), Kogelberg State Forest based on the Marsh Rose *Orothamnus zeyheri* (Boucher 1981b, Luckhoff 1982)). It appears that the large mammals which were exterminated from the Cape Floristic Region never played a major role in the dynamics of nutrient-poor fynbos communities (Skead 1980, Morrow et al 1983). Attempts by provincial and local conservation authorities to introduce large mammals ('big game') into fynbos reserves have failed, owing to lack of grazing and deficiency diseases associated with the nutrient-poor soils

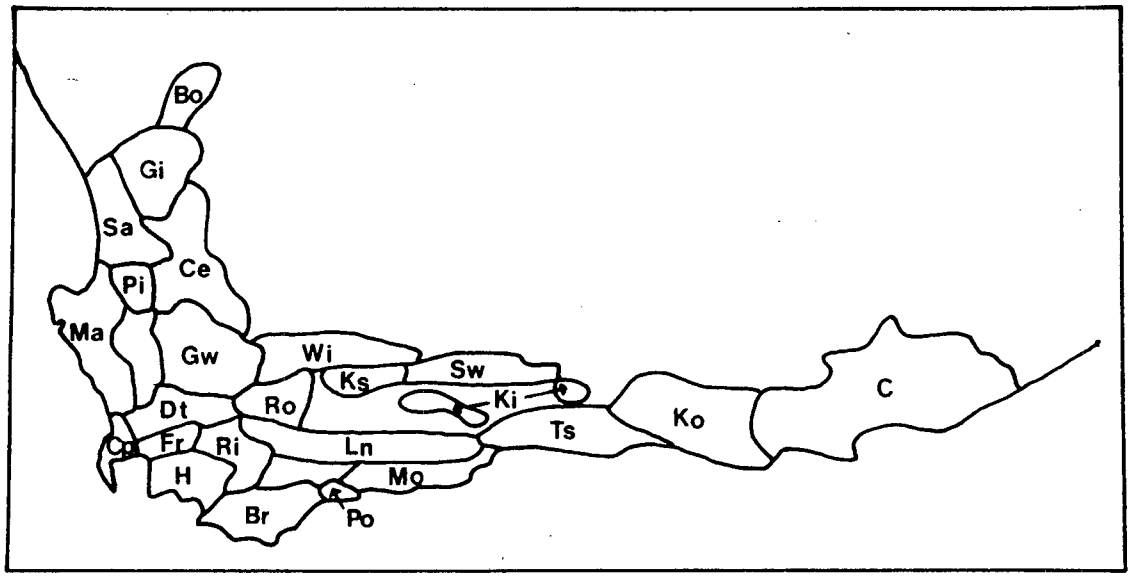

FIGURE 1.1.1 Centres of endemism for Proteaceae in the Cape Floristic Region (Rebelo and Siegfried 1990). Names of centres are given in Table 1.1.3.

(Van Rensberg 1975, Zumpt and Heine 1977).

Large mammal species were apparently confined to non-fynbos (renoster shrubland, thicket and forest) (Skead 1980). Much of the renoster shrubland was apparently derived from a grassland, possibly dominated by *Themeda triandra* (Muir 1929, Skead 1980, Cowling 1984, Cowling et al 1986, Cowling and Holmes MS). Although European stock farming was initiated only in 1703 (Le Cordeur 1986), Skead (1980) suggests that this transformation was complete in the western Cape by 1750. In the southern Cape the transformation appears to have occurred between Sparrman's 1775 travels and the travels of Barrow in 1797 and Burchell in 1814 (Muir 1929). This period probably coincides with the elimination of the large mammals in the region and the start of settled farming (Skead 1980). It certainly precedes the large scale wool-farming that was initiated in the 1820's (Le Cordeur 1986). Since the alleged transformation was completed before the travels of the early naturalists, it is possible that many plant species may have become extinct before the region was explored botanically (Hall and Veldhuis 1985).

The development of the reserve system

By far the largest proportion of preserved land in the Cape Floristic Region (878 000 ha) was proclaimed by the Forestry Directorate of the Department of Environment Affairs as State Forests (Table 1.1.1). The Forestry Directorate was the first to establish reserves in the Cape Floristic Region, primarily in response to the destruction of afromontane forest (Grove 1987). Although established as forestry reserves, which were de facto preserved as water catchment areas, these were without comprehensive protection (Huntley 1978). The importance of preserving water catchment areas was highlighted by research in which annual runoff from mature forest plantations was found to be 50-100 per cent less than that of natural fynbos vegetation (Versveld and Van Wilgen 1986). This resulted in the rapid acquisition of land during the 1960s (Taylor 1978) and strict controls on afforestation, under the Mountain Catchment Areas Act of 1970, to protect South Africa's limited water supply (Greyling and Huntley 1984, Macdonald 1989).

TABLE 1.1.1 Ownership and controlling bodies of reserves in the Cape Floristic Region. Data from the Percy FitzPatrick Institute of African Ornithology data base (Siegfried 1989) and Cowan (1987).

Authority	Area preserved ($X10^3$ ha)	Proportion of total (%)
CDNEC[1]:		
Provincial nature reserves	82	4.6
Former State Forests	878	48.9
Private and local authority nature reserves:		
Subsidized by CDNEC [1]	53	2.9
Non-subsidized [2]	22	1.2
State owned and controlled reserves [3]	69	3.8
Contractual nature reserves [4]	693	38.6

[1] CDNEC = Chief Directorate of Nature and Environmental Conservation of the Cape Provincial Administration.
[2] Private nature reserves and natural heritage sites.
[3] National Botanical Institute, National Parks Board, and South African Defence Force.
[4] Contractual mountain catchment areas and contractual national parks.

Rapid advances in the conservation policies of the Forestry Directorate resulted in the establishment of several wilderness areas and forest nature reserves between 1971 and 1982 (Figure 1.1.2, Kruger 1977). These were established for scientific research in natural ecosystems, aesthetic values they engendered and the physical and spiritual opportunities they afforded (Ackerman 1972). It was planned to transfer one-third of State Forests to wilderness areas, the remainder available for future developments and protected as de facto nature reserves in the interim (Ackerman 1972).

As a result of the government's decentralization policy, the majority of unafforested State Forests were transferred to the Chief Directorate of Nature and Environmental Conservation of the Cape Provincial Administration during 1987-1988 (Hilton-Taylor and Le Roux 1989). It is uncertain whether the Chief Directorate of Nature and Environmental Conservation will be able to maintain the former State Forests as efficiently as the Forestry Directorate, as the costs of alien removal, firebreak maintenance and fire-control were cross-subsidized by the afforestation activities of the Forestry Directorate (Van Wilgen et al MS).

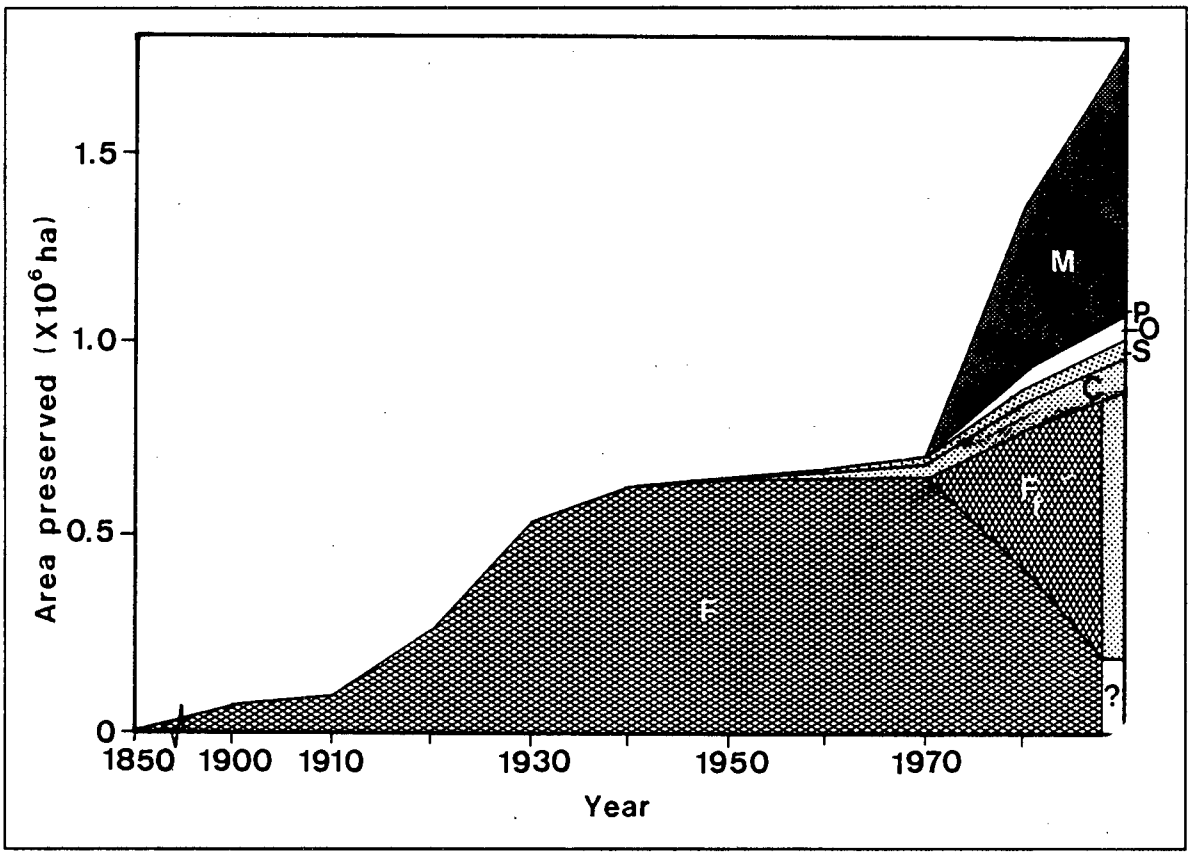

FIGURE 1.1.2 Historical allocation of land to the reserve system in the Cape Floristic Region.
Ownership and management categories are: C = Chief Directorate of Nature and Environmental Conservation (provincial nature reserves); F = former State Forests; S = privately owned, subsidized by Chief Directorate of Nature and Environmental Conservation (subsidized nature reserves); P = privately owned and controlled (private nature reserves and natural heritage sites); O = state owned and controlled (National Botanical Institute, National Parks Board, South African Defence Force); M = contractual nature reserves (Mountain Catchment Areas and National Parks). Note that State Forests (F) only received formal protection between 1970 and 1987 (Ff), after which they were transferred to the Chief Directorate of Nature and Environmental Conservation. A proportion of unafforested State Forests (?) has not been transferred to Chief Directorate of Nature and Environmental Conservation and will probably be used for future afforestation. Data from the Percy FitzPatrick Institute of African Ornithology data base (Siegfried 1989) and Cowan (1987).

The Chief Directorate of Nature and Environmental Conservation has the smallest area preserved of all the provincial authorities (Cowan 1987), despite the Cape Province being the largest province in South Africa. Only 82 000 ha (0.9%) of the Cape Floristic Region area was preserved in provincial nature reserves in 1986. This probably reflects the Department's mission to co-ordinate the interests of inland fisheries, conservation, pest control and museum services. Thus the Department viewed conservation alone as inadequate: 'Wildlife must be regarded as a by-product of wise usage of the land' (Anon 1952). Consequently, management and research was directed towards developing a programme of wildlife management suited to farming conditions (Anon 1952), apparently at the expense of obtaining land for provincial nature reserves. The majority of early provincial nature reserves were acquired for breeding fish and mammals to restock reserves and to sell to private landowners (Scott 1986). During the 1970s emphasis shifted to the preservation of representative vegetation types (Scott 1986). Recently, some provincial nature reserves under the control of the Chief Directorate of Nature and Environmental Conservation have been rezoned or deproclaimed (McDowell et al in press, Wood 1991).

Box 1.1.1 The sanctity of provincial nature reserves has been brought into disrepute with recent urban developments in the Cape Town metropolitan area. In 1987 the Chief Directorate of Nature and Environmental Conservation granted permission for one-third of the Driftsands Nature Reserve to be mined for sand (for road works) prior to that area being transformed into a water-retainer dam to prevent flooding of new suburbs being developed below the reserve. The reserve has been zoned for urban development and is currently under threat of deproclamation (McDowell et al in press). Two provincial nature reserves have recently (December 1990) been deproclaimed, ostensibly because of lack of funds (Wood 1991).

Other state controlled reserves in the Cape Floristic Region include the National Parks Board with five reserves totalling 30 000 ha; the National Botanical Institute which maintains portions of its three national botanical gardens as nature reserves, in addition to two nature reserves, which together total 800 ha; and, the South African Defence Force which has 13 training and military areas (37 000 ha) managed as nature reserves since 1978. Although the state controlled land outside the former State Forests amounts to only 1.7% of the area of the Cape Floristic Region (Table 1.1.1), these reserves are mainly in the lowlands and are thus critical in terms of species and habitats preserved.

Private nature reserves and natural heritage sites comprise the smallest area of conserved land (Table 1.1.1). These have no secure long-term conservation status (Hilton Taylor and Le Roux 1989). Since about 80 per cent of land in the Cape Floristic Region is privately owned, and conservation legislation is emphatically restrictive, inadequately enforced and provides few economic incentives (McDowell 1986a,b), it appears that little increase in the area of private nature reserves can be expected.

Box 1.1.2 A portion of the Elandsberg Private Nature Reserve, the largest private nature reserve which preserves over 90 per cent of individuals of the Geometric Tortoise, was expropriated for an armaments factory (Hall 1981).

Neither do subsidized nature reserves, which are controlled by local authorities and obtain a subsidy and management advice from the Chief Directorate of Nature and Environmental Conservation, appear to have a secure long-term future. Some reserves have been deproclaimed or inadequately managed (McDowell 1986a, Rebelo and Holmes 1988), setting precedents for future deproclamation of other reserves. A reduction and possible withdrawal of subsidies will further threaten their status.

Box 1.1.3 One such reserve, the Kalabaskraal Nature Reserve was proclaimed in 1966 as a major renoster shrubland preserve. It was sold illegally by the Swartland Divisional Council in 1984, who were ordered to re-purchase and reinstate the reserve by the Administrator of the Cape after a public outcry (McDowell 1986a). Due to lack of funds it could not be purchased and was deproclaimed, setting a precedent for future deproclamation of other reserves.

Box 1.1.4 The future of subsidized nature reserves appears bleak, considering that even under Chief Directorate of Nature and Environmental Conservation control, the Kleinmond Municipality was able to use the Kleinmond Coastal Nature Reserve for establishing a new graveyard and night soil pit, to dump large quantities of roadfill, and flower pickers were allowed to harvest flowers to such a degree that one-third of the plants in some populations of *Brunia albiflora* were killed (Rebelo and Holmes 1988), and the status of *Erica pillansii*, which is largely confined to the reserve, was elevated to the 'vulnerable' category in the 1985 Red Data Book for plants (Hall and Veldhuis 1985).

A recent development has been the proclamation of contractual preservation areas as Mountain Catchment Areas (via the Dept of Environment Affairs under the Water Conservation Act 63 of 1970) and contractual national parks (under the National Parks Act 57 of 1976) (Figure 1.1.2). Although these areas are privately owned, they are managed integrally with core nature reserves for purposes of conservation. Management policies include prescribed burning practices, combatting alien invasive plants and controlled grazing (Kruger 1982). Limited and controlled agricultural and urban development is allowed. No assessment of these areas has been published (Hilton-Taylor and Le Roux 1989) and thus their long-term viability is unknown.

The major difference between the management of contractual reserves and state-owned nature reserves is that grazing, game farming, and flower and plant harvesting, on a scale compatible with ecosystem preservation, are allowed in the former (Bands 1985). However an obstacle to the development of contractual reserves is a perceived restriction on farming practices, land speculation and development, which landowners maintain reduces the re-sale value of their land (McDowell 1986a). Nevertheless, contractual nature reserves appear to be the only method by which very large tracts of land can presently be acquired for preservation (Figure 1.1.2), and already they comprise a large proportion of the total area preserved in the Cape Floristic Region.

What is preserved?

Fynbos in the mountains of the Cape Floristic Region currently has more than half its area preserved (Table 1.1.2). Mountain fynbos occupies about half the area of the Cape Floristic Region. Although thicket, renoster shrubland and fynbos of the lowlands comprise about 40 per cent of the Cape Floristic Region, less than three per cent (ca 760 out of 28 500 km^2) is preserved.

Coarse vegetation units are not the ideal units in which to measure biotic diversity. The use of biogeographic regions would be more appropriate (Kruger 1977, Hall and Veldhuis 1985). For fynbos the majority of biogeographic regions in the Cape Floristic Region are very well preserved (Table 1.1.3, Figure 1.1.1); exceptions are the coastal lowlands (Bredasdorp, Malmesbury, Mossel Bay, and Sandveld), associated mountains (Piketberg) and the arid mountainous regions (Bokkeveld, Gifberg and Witteberg). Renoster shrubland is the most poorly preserved vegetation type: in the west and south-west coastal regions less than 10 per cent of the extant vegetation, which in turn comprises only 5 per cent of the original extent, is preserved (Table 1.1.4).

Ideally, the starting point for planning improvements to a reserve network is to ascertain which species are preserved in existing reserves (Siegfried 1989). Unfortunately, published checklists are available for only 15 per cent of reserves in South Africa, with plants being especially poorly documented (Siegfried

1989). The PRECIS database of plant species present in the National Herbarium at Pretoria (Gibbs Russell and Gonsalves 1984), together with data from local herbaria, should allow an assessment of preservation status. However, the PRECIS data base is inadequate, owing to the quarter-degree grid (ie 24X27 km) scale used being too coarse (Rebelo and Siegfried 1990) and a ±30 per cent error in distribution records in terms of species (Rebelo and Cowling submitted). Based on the Proteaceae, Rebelo and Siegfried (1990) estimate that 93 per cent of mountain fynbos plant species are protected in the existing reserve network. No estimates are available for renoster shrubland or lowland vegetation types.

TABLE 1.1.2 Changes in the conservation status of vegetation types (based on Acocks (1975)) within the Cape Floristic Region. Vegetation categories in parenthesis refer to types described by Cowling & Holmes (MS).

Acocks Veld Type	Total area ($X10^3$ha)[1]	Per cent of total area protected					Natural area remaining[1]
		1974[2]	1983[3]	1987[4]	1989[5]	Herein[6]	(%)
Knysna forest (afromontane)	384.4	47.9	3.5	4.3	-	-	76
Strandveld (dune thicket)	445.3[7]	1.1	0.5	0.5	0.7	6.8	76
Renosterveld:							
mountain (renoster shrubland)	475.4	0.0	12.1	1.5	2.3	1.3	73
coastal (renoster shrubland)	1528.5	0.9	0.6	0.5	2.5	0.3	15
Macchia:							
coastal (fynbos)	877.0	2.1	2.4	1.8	4.7	3.3	53
mountain (fynbos)	1834.5	15.3	33.6*	54.0* (28.3)	53.1	52.6	89
false (fynbos, grassy fynbos)	1896.5	21.1	2.2*	2.0* (26.9)	19.6	47.6	97

[1] Moll and Bossi (1984): estimates for Acocks (1975) veld types.
[2] Edwards (1974): Nature reserves and unafforested State Forest land.
[3] Scheepers (1983): As above.
[4] Cowan (1987): Includes private and state Mountain Catchment Areas.
[5] Hilton-Taylor and Le Roux (1989): Includes private and state Mountain Catchment Areas.
[6] Data from Tables 1.1.3 and 1.1.4 (Siegfried 1989). Vegetation types do not correspond exactly. Data as for Cowan (1987), but include private nature reserves and unafforested State Forest land in the east of the region (ie 'false fynbos').
[7] Excludes portion beyond the Cape Floristic Region.
* Data for the fynbos types from 1983 to 1985 are incorrect partly due to differences in the vegetation type classifications used. Recomputed values (from Cowan (1987)) are presented in parentheses.

TABLE 1.1.3 Areas currently reserved and proposed for preservation of fynbos vegetation in the major phytogeographic zones of the Cape Floristic Region. The codes refer to the areas depicted in Figure 1.1.1.

District	Code	Total extant area[1] of fynbos (ha)	Area conserved[2] (ha)	Proportion conserved (%)	Area proposed (ha)[2]	Proportion proposed (%)[3]	No. reserves exist A	exist B	prop.
The Northwestern Province									
Cedarberg District	Ce	256 900	221 601	86	0	0	3	3	0
Great Winterhoek District	Gw	220 600	162 092	73	1 750	1	7	4	1
Piketberg District	Pi	49 360	0	0	23 200	47	0	0	2
Sandveld District									
Sandveld Zone	Sa	230 600	0	0	27 500	12	0	0	2
Bokkeveld Zone	Bo	85 000	5 070	6	0	0	1	0	0
Gifberg Zone	Gi	237 000	0	0	0	0	0	0	0
The Southwestern Province									
Malmesbury District	Ma	97 200	3 409	4	57 339	59	13	0	17
Peninsula District	Cp	27 800	27 755	100	0	0	10	1	0
Riviersonderend District	Ri	91 200	73 157	80	0	0	4	2	0
Franshoek District	Fr	59 600	58 519	98	1 100	2	7	4	1
DuToitskloof District	Dt	136 900	122 212	89	16 300	12	8	2	11
Houwhoek District	H	99 100	64 416	65	41 325	42	14	2	6
Bredasdorp District	Br	231 700	17 699	8	68 450	30	16	1	7
Potberg District	Po	13 000	2 500	19	500	4	1	0	1
Mosselbay District	Mo	154 900	2 705	2	680	0.4	5	0	1
Coastal Mountain Province									
Koo Langeberg District	Kl	72 200	59 936	83	0	0	4	1	0
Langeberg District	Ln	185 300	85 023	46	10 950	6	5	4	4
Outeniqua District	Ou	161 900	156 043	96	19 001	12	33	5	8
Kouga District	Ko	665 800	178 213	27	36 632	6	18	4	6
Southeastern Province									
Cockscomb District	C	260 100	150 288	58	105 250	40	23	5	8
Inland Mountain Province									
Swartberg District									
Swartberg Zone	Sw	121 600	121 600	100	0	-	3	1	-
KleinSwartberg Zone	Ks	57 400	57 000	99	0	0	5	2	0
Karoo Island Zone	Ki	168 500	55 250	33	0	0	4	3	0
Witteberg District	Wi	16 100	0	0	0	0	0	0	0
Total		3 699 760	1 624 688	43.9	409 925	11	184	44	75
Total original area		4 608 000		35.3%		9%			

A = total number of reserves; B = reserves larger than 100 km^2

[1] Calculated from Moll and Bossi (1984).

[2] Data from the Percy FitzPatrick Institute of African Ornithology data base (Siegfried 1989).

3 Jarman (1986)

[4] Proposed conservation areas include areas within Mountain Catchment Areas. Therefore proposed and existing conservation areas may exceed 100% in total.

TABLE 1.1.4 Areas currently preserved and proposed for conservation in the major non-fynbos vegetation types in the Cape Floristic Region.

	Total extant area of vegetation[1] (ha)	Area conserved[2] (ha)	(%)	Area proposed for conservation[3] (ha)	(%)	Area transformed by agriculture[4] (ha)	(% total)
Renoster shrubland							
West coast	27 294	2 484	9.1	12 198	44.7	637 497	95.9
South-west coast	19 984	660	3.3	8 505	42.6	469 582	95.9
South coast	356 994	2 935	0.8	40 320	11.3	414 633	53.7
Central mountain	581 336	8 865	1.5	6 350	1.1	71 443	10.9
Total	985 608	14 944	1.5	67 373	6.8	1593 155	61.8
Thicket[5]							
West coast	192 049	27 335	14.2	53 287	27.7	213 611	52.7
South coast	130 628	12 590	9.6	17 724	13.6	6 076	4.4
Total	322 677	36 713	11.4	71 011	22.0	219 687	40.5

[1] Moll and Bossi (1984).
[2] Jarman (1986) and Cowan (1987).
[3] Jarman (1986).
[4] Estimated from Moll and Bossi (1984).
[5] Mosaic of dune thicket, and fynbos.

Status of nature reserves

Although it has become standard to consider most preserved areas as 'nature reserves' in the Cape Floristic Region, these reserves encompass widely diverging management objectives. Thus, emphasis in the acquisition of provincial nature reserves has been the preservation of Bontebok *Damaliscus dorcas dorcas*, Mountain Zebra *Equus zebra zebra*, Geometric Tortoise *Psammobates geometricus*, feeding and roosting areas for wading birds and fish breeding. Many subsidized nature reserves are managed as botanical gardens, game farms, reclaimed agricultural lands, and other activities incompatible with classical conservation concepts. Management practices geared towards maintaining large mammals in fynbos (eg Cape of Good Hope Nature Reserve, De Hoop Nature Reserve, Bontebok National Park), may result in degradation of natural vegetation by too-frequent burning, bushcutting, input of fertilizers and trace elements (eg from salt-licks), provision of drinking troughs, and planting of pasture grasses (Van Rensburg 1975, Zumpt and Heine 1977, Novelli 1986, Scott 1986, Van Wilgen et al MS, D Clark personal communication). That the environment is degraded by these 'habitat improvement' activities suggests that resident, large mammals are not an integral part of the ecology of fynbos. By contrast, the breeding biology of the Geometric Tortoise requires a fire regime compatible with flora preservation, so that management practices aimed at maintaining tortoises effectively preserves the

natural habitat (Greig 1981, Van Wilgen et al MS).

Although a classification of nature reserves on the basis of management goals is urgently required, data are not available for the majority of subsidized and private nature reserves. In addition, the management policies for the State Forests acquired by Chief Directorate of Nature and Environmental Conservation are still being formulated. A thorough review of management strategies of reserves in the Cape Floristic Region is long overdue.

Box 1.1.5 Management strategies will have to be scrutinized carefully. For instance, most of the Tsistikamma Mountains will be managed as a triple-lane fire break (each 3 km wide), each break to be burned at 9 year intervals in a three-year rotation cycle (N de Waal personal communication). This is clearly incompatible with the preservation of fynbos plant species, the majority of which only commence reproduction between 4 and 12 years after a fire (Le Maitre 1987, Van Wilgen et al MS). A thorough review of management strategies of reserves in the Cape Floristic Region is long overdue.

CONFIGURATION OF RESERVES AND THE RESERVE NETWORK

Assuming that the goal of a conservation strategy is to preserve maximum biotic diversity in a minimal area, then three aspects must be considered: the number of reserves, their location and their size. It is the location of individual reserves and their relative contribution towards preserving total species richness which determines the number of reserves required (Rebelo and Siegfried submitted). The optimal location of reserves is determined primarily by centres of endemism, with species turnover and relative species richness contributing to the total number of reserves required (Rebelo and Siegfried submitted). Because of practical considerations, the size of reserves is usually determined by factors other than preserving biotic diversity per se and will be considered later.

Three major prescriptions have been made over the past half century for the preservation of fynbos. Wicht (1945) sought to preserve Fynbos for its aesthetic and general scientific value, with the primary objective of conserving the native vegetation in reserves comprising 'well selected, representative, relatively large regions, which should be maintained with painstaking care'. Five reserves were designated as the core of this reserve configuration (Table 1.1.5), with numerous additional, unspecified, local reserves mooted. Kruger (1977) considered the optimum strategy to place reserves so as to represent different fynbos vegetation types. In the absence of a classification with the desired resolution, he used major fynbos vegetation types within biogeographic regions as the basis for designating nineteen zones requiring preservation (Table 1.1.5). Based on the distribution of Proteaceae species, Rebelo and Siegfried (1990) used transects comprising 12X13 km grid squares through areas of high species richness to determine the location of reserves required to preserve each species in at least one reserve.

The dynamics of reserve allocation in the Cape Floristic Region was investigated by Rebelo and Siegfried (submitted), using an iterative approach (Pressey and Nicholls 1989a,b) and the distribution of Proteaceae species on a 12X13 km square grid (Figure 1.1.3a). All Proteaceae species can be preserved at least once in a reserve system of 53 grid squares (Figure 1.1.3a) or 17 per cent of the total area of fynbos (although the area of 20 reserves (= grid squares) protecting one or two species could perhaps be less than 156 km^2). To preserve each species in at least two reserves requires slightly less than double the area above, whereas preserving each species in five reserves requires four times the area, and in 10 reserves requires six times the area. The configuration of these reserves validates Kruger's (1977) approach of placing a reserve in each biogeographic zone, but indicates that

more reserves are required in the more species-rich areas.

The use of the Proteaceae as representative of total taxa for the Cape Floristic Region is considered valid, since species richness of Proteaceae is significantly correlated to total species richness, as well as to species richness in all the major fynbos families (Ericaceae, Restionaceae, Bruniaceae, Rutaceae: Diosmae, Penaeaceae) and some larger genera (*Aspalathus* (Fabaceae), *Muraltia* (Polygalaceae)) at a quarter-degree (24X27 km) grid square scale (Rebelo and Siegfried 1990). This suggests that similar factors influenced speciation and dispersion in the major fynbos families. It is not known over what range of grid-scales the relationship holds.

TABLE 1.1.5 Summary of the history of proposed nature-reserve networks for fynbos vegetation in the Cape Floristic Region. Reserves are numbered in order of decreasing importance.

Vegetation type[1]	Biogeographic centre (Weimarck 1941)	Wicht (1945)	Kruger (1977)	Rebelo & Siegfried (1990)[2]
Mountain fynbos	**North-western Centre**			
	Cedarberg subcentre	1. Cedarberg	7. Cedarberg	P6,S2
	Great Winterhoek subc		8. Groot Winterhoek	P7,P13,S3
	South-western Centre			
	French Hoek subcentre	2. Drakenstein -Kogelberg	10. Southern	P1,P12,S1,S6,S7
			11. Riviersonderend	P3,S9
	Hottentot Holland subc		9. Northern	P11
	Peninsula subcentre			P5
	Karoo mountain Centre	3. Swartberg	12. Swartberg	P8
			13. Little Karoo Islands	S10,S11,S12
	Langeberg Centre	4. Lemoenshoek	14. Lemoenshoek	P4
	(Potberg 'island')			P9
	Knysna Centre	5a.Outeniqua	15. Outeniquas	P14
	South-eastern Centre			
	Zitzikamma subcentre	5b.Tsitsikamma	17. Tsitiskamma	-
	Cockscomb subcentre		16. Kouga river drainage	P15
			18. Winterhoek Mountains	S5
	Zuurberg subcentre		19. Zuurberg	-
Coastal fynbos	**South-western Centre**			
	Malmesbury subcentre		1. West coast	P10,S4
	Bredasdorp subcentre		2. S coast - Elim flats	P2
	Langeberg Centre		3. S coast - limestone	S8
Arid fynbos	**North-western Centre**		4. Witteberg mountains	S12
	Karoo mountain Centre		5. East	S11
			6. West	S10

[1] Sensu Kruger (1977) and Taylor (1978), based on Moll et al (1984). Arid fynbos refers primarily to asteraceous and restioid fynbos from the dry north and north-west of the region, and in the rain-shadows of the Langeberg and Cedarberg mountains.

[2] P = primary reserves, S = secondary reserves.

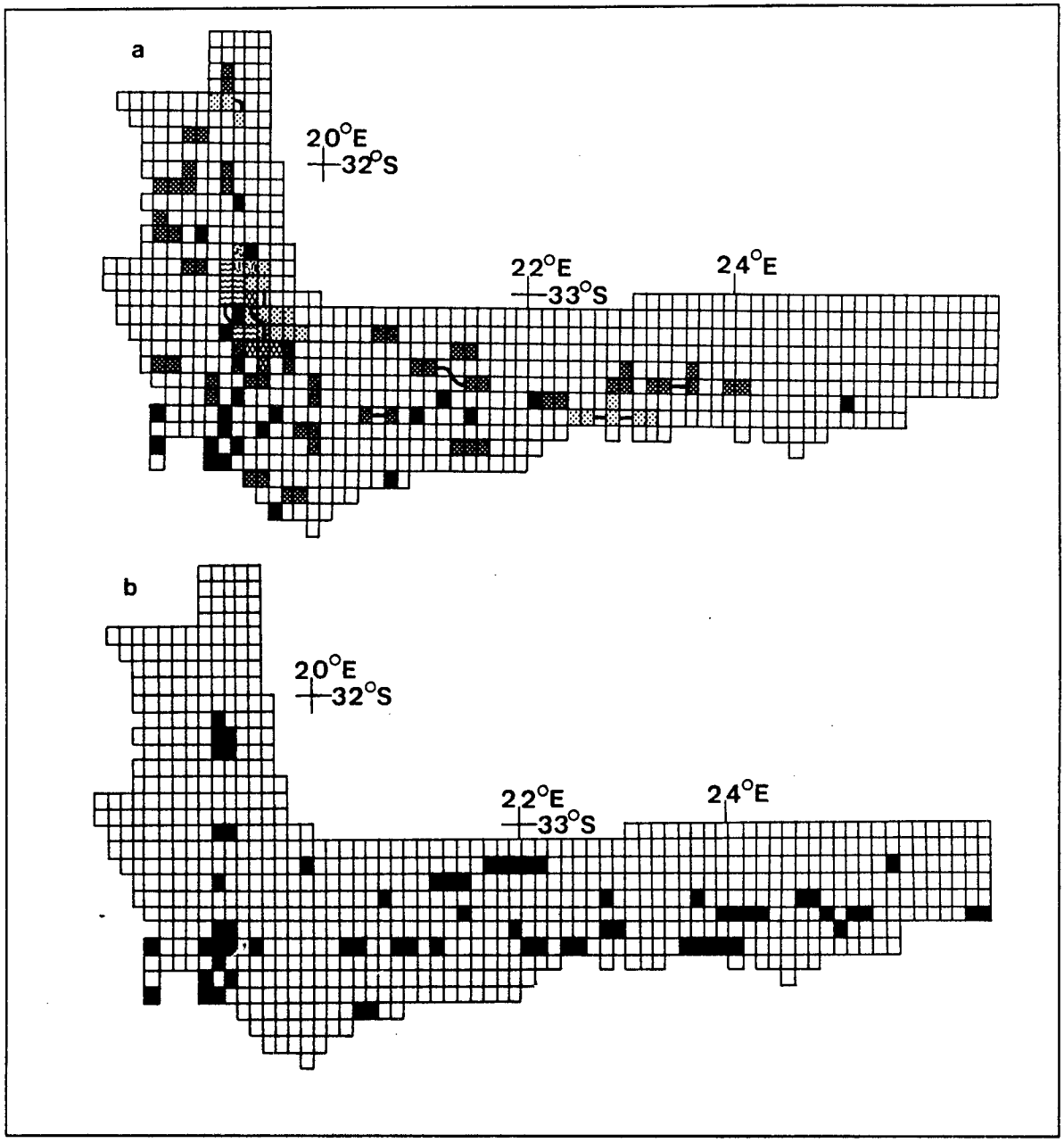

FIGURE 1.1.3 a) The spatial configuration of an optimal nature-reserve network for fynbos vegetation in the Cape Floristic Region (Rebelo and Siegfried submitted), based on an iterative model using the distribution of Proteaceae species in an eighth-degree grid (12X13 km). A reserve was selected, at each iteration, as the grid square containing the highest sum of rarity scores for all species not adequately preserved, where the rarity score equals the inverse of the proportion of total grid squares occupied by the species. Solid blocks are squares invariably selected as reserves. Shaded blocks indicate reserves for which several grid squares are equally suitable and solid lines connect squares which are not orthogonally adjacent. Different shading separates different adjacent reserves. b) The distribution of State-owned reserves in the Cape Floristic Region. Solid blocks have more than 55 per cent (8 000 ha) of the total area (14 400 ha) preserved (Rebelo and Siegfried 1990).

Assuming that all grid squares containing reserves which comprise greater than 50 per cent of their area adequately preserve all species present, then the existing reserve configuration (Figure 1.1.3b) preserves 80 per cent of fynbos species. The major gaps identified in the reserve network agree with the conclusions derived from an analysis of area preserved in biogeographical zones (Table 1.1.3); viz the lowlands and arid areas are not adequately preserved (Rebelo and Siegfried 1990).

Note that the above network considers only the preservation of maximum species richness in a minimal area. Nothing is known about the importance of corridors, sink-source areas in fynbos, or the seasonal importance of other vegetation types in supplying species for pollination, seed dispersal or predation, in determining the spatial configuration of the reserve network.

CONSERVATION PRIORITIES

A variety of approaches exist for assessing areas for preservation (Margules and Usher 1981). To date, only a single attempt at prioritizing areas for preservation in the Cape Floristic Region has been undertaken (Jarman 1986), and this was confined to an appraisal of the lowlands. The results of this survey formed the basis for the NAKOR National Plan for Nature Conservation (Burgers et al 1987). Sites of existing natural vegetation were ranked according to the rarity of the vegetation type, habitat diversity, species and rare species richness, the size and shape of the area, and its proximity to neighbouring sites. A major omission from the analysis was an assessment of the degree of threat. Consequently, it has favoured the acquisition of large reserves, far removed from any threat, at a fraction of the cost per unit area of small potential reserves, under imminent threat of agricultural and urban transformation.

Suitable data bases for assessing priority areas include Red Data Books and analyses of major threats to species in the Cape Floristic Region. Red Data Books for all vertebrate orders (Brooke 1984, Smithers 1986, Skelton 1987, Branch 1988), plants (Hall et al 1980, Hall and Veldhuis 1985) and butterflies (Henning and Henning 1989) are available for South Africa. These list threatened and naturally rare species and summarize existing autecological information (Ferrar 1989). With the exception of birds and large mammals, many of which are still common in South Africa but extinct or threatened in the Cape Floristic Region, few threatened species are shared between the Cape Floristic Region and the rest of South Africa (Rebelo submitted). A regional compilation of extinct, threatened and rare mammal and bird species (Rebelo submitted) was undertaken for the Cape Floristic Region.

What are the threats?

Agriculture has had the largest impact on vegetation types in the Cape Floristic Region (Table 1.1.6). Its effect has been largely confined to the lowlands and is most prominent in renoster shrubland, with its conversion to primarily wheat lands, vineyards and pastures (Boucher 1981a, Hall 1981). Lowland fynbos and thicket have been largely converted to pasture (Rebelo et al 1991). Alien invasive plant species, together with agriculture, account for the bulk of habitat destruction in the Cape Floristic Region. Unlike agriculture, removal of aliens may result in recovery of vegetation (Richardson et al MS). Although urbanization accounts for less than one per cent of the area of the Cape Floristic Region, it is largely concentrated in the greater Cape Town metropolitan area (Macdonald 1989). In a survey of the 484 ha of lowland fynbos remaining in the ca 30 000 ha metropolitan area, McDowell et al (in press) found 74 Red-Data-Book Plant taxa, a ratio of 15.3 species per km^2. Much of the coastal area immediately adjacent the sea (mainly thicket) is under threat from resort development (Cowling and Pierce 1985, Jeffery and Moll 1987). National

legislation to restrict such development within 1 km of the coastline is not enforced by provincial authorities. Dams cover an insignificant area of the Cape Floristic Region (ca 1.3%, including farm dams) (Macdonald 1989), but became a major conservation issue following a proposal to dam the lower Palmiet River in the Kogelberg State Forest (Roberts 1982). Water is extracted from underground aquifers along the West coast for urban consumption, and is apparently drying up perennial streams in the area (FW Duckitt personal communication).

A similar pattern is evident for overall threats to specific Red Data Book species (Table 1.1.7). Agriculture and alien invasive plants contribute significantly to species decline in the Cape Floristic Region. However, threats vary considerably among groups (Table 1.1.7). Thus birds and large mammals have largely been hunted and poisoned (Brooke 1984, Smithers 1986), whereas reptiles are especially susceptible to collecting for the pet trade (Branch 1988), fish to predation by introduced alien fish (Gaigher et al 1980, Skelton 1987), and butterflies to coastal development (Henning and Henning 1989). Whereas the majority of threats involve an obvious human impact, the importance of fire emphasizes the need to maintain natural disturbance regimes (Van Wilgen et al MS). Interestingly, fire has been identified as a threat to frogs, but not to fish, possibly reflecting differing perceptions to fire (independent of its effects on water discharge) by compilers of Red Data Books. Although, hybridization has been recorded only as a threat to frogs and small mammals, the transfer of genes between populations and species of plants through the establishment of wild flower gardens probably occurs more frequently among widespread species than is realized.

Although 68 per cent of the plants in the Cape Floristic Region are endemic, only 15 per cent are listed in the Red Data Book, and only three per cent are threatened (Table 1.1.8). Of these, typical fynbos families (Proteaceae, Ericaceae and Rutaceae) appear most threatened. Mammals are the most seriously threatened (14% of species) of taxa, but this is largely due to the extinction, by hunting, of large carnivores and ungulates with widespread distributions. Some 60 per cent of mammals over 50 kg have been eliminated from the Cape Floristic Region (Rebelo submitted), although many species have been reintroduced. Amphibians, with 13 per cent threatened, have a quarter of their endemic species threatened. Overall threats to amphibians and reptiles do not appear to differ among families, although the pet trade is the greatest threat to Girdled Lizards (Cordylidae) and Tortoises (Chelonii) (Branch 1988). Among birds, larger species from the scavenging, predatory and plant-invertebrate feeding guilds are most threatened, mainly by hunting and poisoning (Brooke 1984). The Lycaenidae account for the vast majority of Red Data Book Butterflies, and account for 82 per cent of the species endemic to the Cape Floristic Region. Lycaenidae account for all of the threatened species in the Cape Floristic Region (Table 1.1.7), probably because of their association with both specific food plants and ant-host species (Henning and Henning 1989). Urbanization and coastal development are the greatest threat to butterfly species in the region (Table 1.1.7).

In summary, although different taxa are threatened by different factors, agriculture and alien plant invasions are the greatest overall threats to indigenous plants, animals and ecosystems in the Cape Floristic Region.

TABLE 1.1.6 Threats to vegetation types within the Cape Floristic Region. Threats are categorized as high (H), medium (M), low (L), or no threats known (0). Where data are available, the area transformed by the threat is given as a percentage of total area of the vegetation type.

Threat	Fynbos		Renoster shrub		Thicket	Afromont. forest	Karroid shrubland
	mountain	lowland	mountain	lowland			
Agriculture & afforestation[1,2]	7	49	11	79	41	24	L
Alien invasives:							
Fabaceae[3]	10	36	0	7	43	M	L
Hakea & *Pinus*[3]	26	0	0	4	7	0	0
Urbanization[2]	L	M	L	L	H	L	L
Dam building[2]	M	0	M	L	0	L	0
Water extraction	0	0	L	0	H	0	?

[1] Moll and Bossi (1984); [2] Macdonald et al (1985); [3] Macdonald (1989)

TABLE 1.1.7 Threats to plant and animal taxa in the Cape Floristic Region listed as endangered or vulnerable in the Red Data Books. Fo each taxon, the number of species in the largest threat category has been scaled to equal 10. Data from Rebelo (submitted).

Threat	Score								Rank of threat
	Plant		Butterfly	Fish	Amphibian	Reptile	Bird	Mammal	
	Elim[1]	Total[2]							
Agriculture	4.4	5.3	8.9	9.0	10.0	10.0	1.3	1.5	46.0
Alien invasive plants	10.0	10.0	4.4	6.0	0	4.0	0	0	24.4
Hunting/poisoning	-	-	0	0	0	0	10.0	10.0	20.0
Fire (frequency and season)	2.3	3.7	5.6	0	2.5	2.0	2.5	0	16.3
Urbanization/industrialization	5.6	3.8	10.0	1.0	0	0	0	0	14.8
Commercial collecting	1.6	1.3	?	0	0	10.0	0	0	11.3
Dams/wiers/roads	1.7	0.9	2.2	4.0	2.5	0	1.3	0	10.9
Alien predators	-	-	0	10.0	0	0	0	0	10.0
Pollution[3]	0.2	0.4	0	4.0	5.0	0	0	0	9.4
Afforestation	1.0	0.9	2.2	0	2.5	2.0	1.3	0	8.9
Mining/quarrying	0.8	1.2	0	1.0	0	4.0	0	0.5	6.7
Grazing/browsing	0.8	2.9	0	0	0	0	3.8	0	6.7
Hybridization	?	?	0	0	2.5	0	0	0.5	3.0
Intolerance of human presence	-	-	0	0	0	0	2.5	0	2.5
Casual flower picking	1.5	0.2	-	-	-	-	-	-	0.2
Genetic decline[4]	4.5	1.1	0	0	0	0	0	0	1.1
Mowing/human trampling	0.8	1.0	-	-	-	-	-	-	1.0
Number of spp in the largest threat category	49	84	9	10	4	5	8	20	

[1] Data for the plant species of the Agulhas region (Hall & Veldhuis 1985). Typically for fynbos, little agricultural transformation has occurred: consequently this threat is under-represented relative to the entire Cape Floristic Region. This value does not contribute to the total 'rank of threat'.
[2] Data for 232 species for which threats are listed in Hall & Veldhuis (1985)
[3] Including: Fertilizers, pesticides, salinization, acid rain.
[4] Speculative assessment due to inbreeding depression and stochastic processes inherent to small populations.

TABLE 1.1.8. Endemic and threatened (extinct, endangered or vulnerable) species in families containing the most Red Data Book species in the Cape Floristic Region (CFR). Values in parentheses are the percentage of the total number of species in the Cape Floristic Region accounted for by the subtotal. Data from Rebelo (submitted).

	No of species							
	Total		Endemic Book		Red Data		Threatened	
Plants								
Proteaceae	320		306		131		65	
Iridaceae	612		485		242		51	
Ericaceae	688		666		138		31	
Rutaceae	259		242		103		22	
Asteraceae	986		608		166		13	
Fabaceae	644		525		110		10	
Subtotal	3509	(41)	2834	(48)	890	(67)	192	(68)
Total for CFR	**8600**		**5865**		**1326**		**281**	
Butterflies								
Lycaenidae	143	(61)	59	(82)	52	(96)	6	(100)
Total for CFR	**234**		**72**		**54**		**6**	
Fish								
Cyprinidae	15	(54)	11	(73)	10	(83)	5	(71)
Total for CFR	**28**		**15**		**12**		**7**	
Amphibians								
Heliophrynidae	4		4		2		2	
Ranidae	13		4		2		1	
Subtotal	17	(45)	8	(42)	4	(57)	3	(60)
Total for CFR	**38**		**19**		**7**		**5**	
Reptiles								
Sauria: Cordylidae	14		4		3		1	
Serpentes: Colubridae	25		0		3		1	
Sauria: Gekkonidae	18		3		3		0	
Subtotal	57	(52)	7	(36)	9	(53)	2	(60)
Total for CFR	**109**		**19**		**17**		**5**	
Birds								
Falconiiformes	22		0		6		5	
Gruiformes	15		0		7		4	
Subtotal	37	(13)	0	(0)	13	(62)	9	(75)
Total for CFR	**288**		**6**		**21**		**12**	
Mammals								
Carnivora	27		0		11		7	
Artiodacyta	20		2		10		8	
Perissodactyla	5		0		3		3	
Subtotal	52	(41)	2	(22)	24	(65)	18	(86)
Total for CFR	**127**		**9**		**37**		**21**	

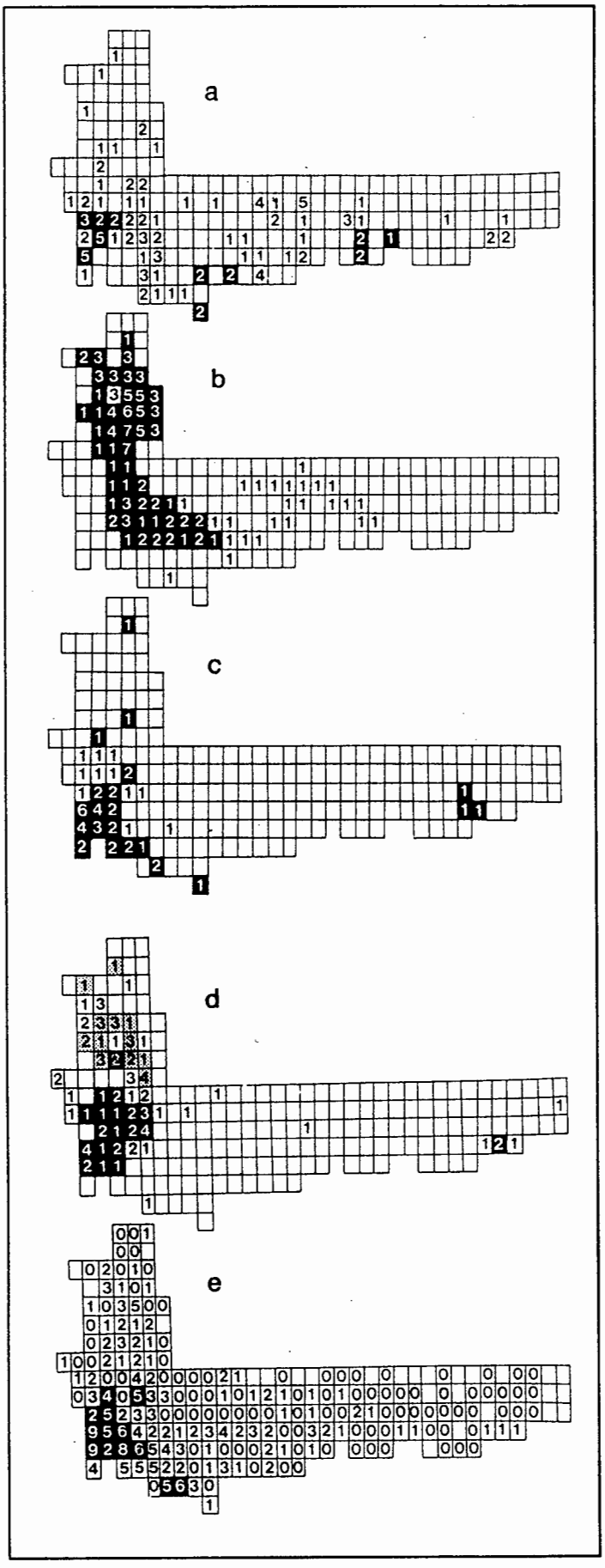

FIGURE 1.1.4 Species richness of Red Data Book species by quarter-degree grid squares (24X27 km) in the Cape Floristic Region. Numerals indicate the number of species, except for plants, where 0 = 1-9, 1 = 10-19, etc. Shaded blocks denote the presence of at least one threatened (extinct, endangered and vulnerable) species, except for plants where it denotes more than 15 threatened species. a) butterflies; b) fish; c) amphibians; d) reptiles (light shading refers to a species threatened by commercial pet collecting); e) plants. Data from Rebelo (submitted)

Priority areas: where are the threats greatest?

Areas richest in Red Data Book species are shown in Figure 1.1.4. Mammals and birds are excluded, but these would almost certainly have been most abundant in non-fynbos vegetation (Skead 1980). The Bontebok and extinct Bluebuck *Hippotragus leucomelas* were apparently endemic to renoster shrubland of the southwestern coast (Smithers 1983), and Buffalo and Elephant were most frequently encountered along the south and east coast (Skead 1980). It cannot be ascertained from historical records whether Quagga occurred in large numbers in the lowlands or were largely confined to karroid & renoster shrubland of the interior mountains (Bateman 1961, Skead 1980, Smithers 1983, 1986, Rookmaaker 1989).

Red Data Book amphibians, reptiles, butterflies and plants are concentrated in the greater Cape Town metropolitan area, encompassing the Cape Peninsula and adjacent Cape Flats (Figure 1.1.4). Of the 82 Red Data Book plant species in the lowlands of the metropolitan area, 74 occur in fynbos and eight in thicket vegetation (McDowell et al in press). Similarly, most amphibians occur in acid waters associated with fynbos vegetation. A minor node of species richness in the Van Stadensberg area near Port Elizabeth is shared by Red Data Book reptiles, amphibians, butterflies and plants (Figure 1.1.4).

Only fish have a divergent pattern from the above. The majority of endemic fish appear to have arisen from the confluence of the Orange and Olifants Rivers between the Palaeogene and Miocene (Dingle and Hendey 1984). Subsequent river capture of the Orange to the north resulted in the isolation of the Olifants River System and the evolution of eight extant endemic species (Skelton 1987). Agriculture and predatory sport fish have restricted many of these endemics to the upstream portions of their previous distribution range (Gaigher et al 1980, Scott and Hamman 1984, Skelton 1987). The species in the river systems of the south and west coast tend to be generalists, but are usually absent from areas adjacent to agriculture (Scott and Hamman 1984, Skelton 1987).

Unfortunately, detailed data at a quarter-degree grid scale on the distribution of common species are not available, so that patterns of species richness are not available for taxa other than plants. For plants, the richness of Red Data Book species is strongly positively correlated with that of total species richness (Rebelo and Tansley submitted). Furthermore, for the Proteaceae, the distribution of non-Red Data Book species is also strongly correlated with

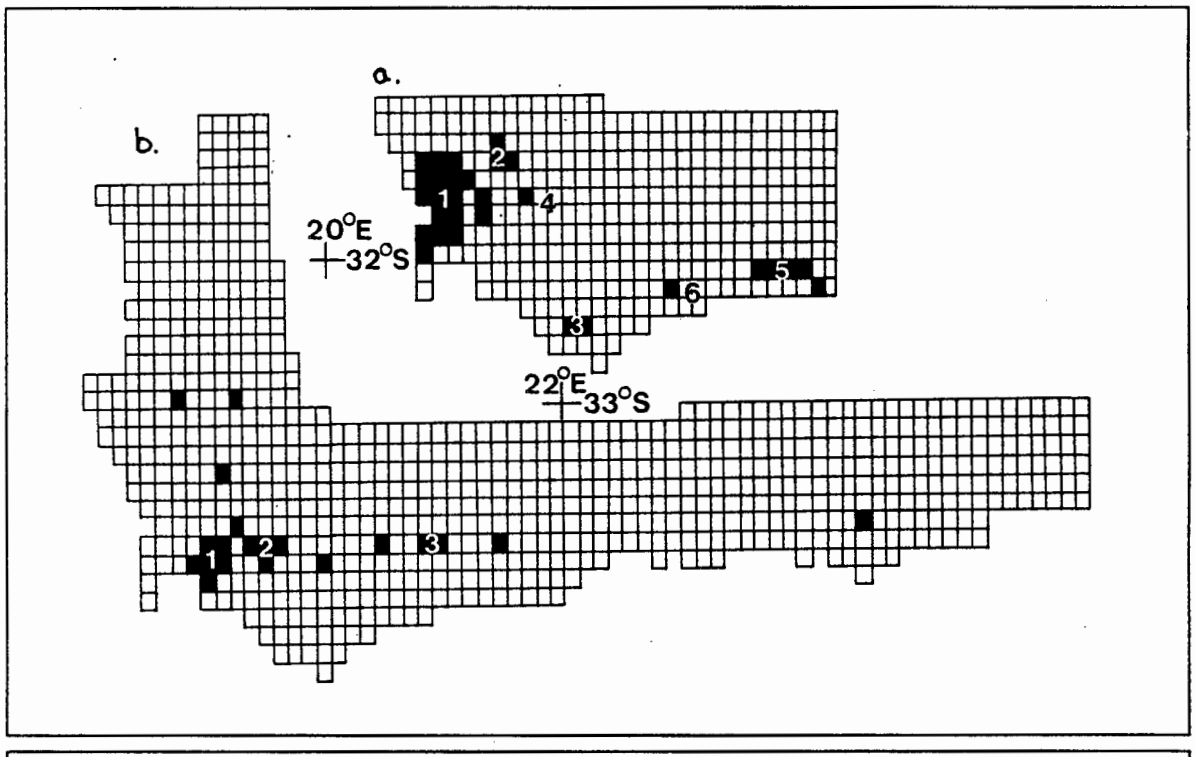

FIGURE 1.1.5 Priority areas for conservation in the Cape Floristic Region based on the distribution of a) threatened (extinct, endangered and vulnerable) and b) naturally rare (rare) Proteaceae species. Shaded blocks (12X13 km) lie outside the 95 per cent prediction limits of the regression of threatened or naturally rare species against total Proteaceae species richness (Rebelo and Tansley submitted).

total species richness. Thus, rare (Red Data Book) species tend to occur in areas which are also rich in non-Red Data Book species (Rebelo and Tansley submitted). Analyses of threatened Red Data Book species will therefore be biased by species richness, and should be corrected for species richness before geographical patterns of threats can be determined.

The dispersion of grid squares with significantly more threatened (extinct, endangered and vulnerable) Proteaceae species, relative to that predicted by regression analysis from the total number of Proteaceae species, are largely confined to the lowlands, with the Cape Peninsula and Cape Flats being the highest ranked area (Figure 1.1.5; Rebelo and Tansley submitted). This is primarily due to urban expansion of the greater Cape Town metropolitan area over much of one of the richer centres of endemism within the Cape Floristic Region (Figure 1.1.1).

The most urgent strategic requirement for preservation of biotic diversity in the Cape Floristic Region is thus within the greater Cape Town metropolitan area. This should involve the acquisition of nature reserves and corridors with emphasis on lowland fynbos communities, specifically the large areas to the immediate north, as proposed by Jarman (1986).

The areas with high numbers of threatened species are quite distinct from those containing more naturally rare (ie rare or critically rare) Red Data Book species than predicted from total Proteaceae species richness. Areas of high naturally rare species are concentrated in the high mountains of the south-west, with several minor, isolated outliers (Figure 1.1.5). Provided that the State Forests in these centres continue to be preserved, large scale extinction of naturally rare species in the Cape Floristic Region could be avoided.

Note that these results relegate renoster shrubland to a far lower priority than suggested by Jarman (1986). This may be because renoster shrubland is poor in locally endemic species (Cowling et al MS). More data are urgently required on the distribution and abundance of renoster shrubland species.

EFFECTIVE RESERVE SIZE

Sizes of existing reserves

Forty nine (20%) of the 244 reserves in the Cape Floristic Region are larger than 10 000 ha (Figure 1.1.6). More than half of these were formerly State Forests, 17 are contractual reserves (accounting for 94% of the contractual reserves), and six reserves are controlled by other authorities. The large majority of these reserves are in the mountains and preserve fynbos. There is only one fynbos reserve in the lowlands greater than 10 000 ha. No renoster shrubland reserves are larger than 10 000 ha. Many of these reserves are contiguous, particularly contractual reserves which usually abut on state-owned reserves, so that effective reserve sizes in the mountains are often larger than 100 000 ha. Similarly, some State Forests consist of isolated mountain peaks, but these are usually surrounded by contractual reserves.

Some 105 reserves (43%) are smaller than 500 ha (Figure 1.1.6). These comprise the majority of private and subsidized reserves. Only four renoster shrubland reserves exceed 500 ha in size, whereas other vegetation types contain many reserves larger than 500 ha. Forty two reserves (17%) are less than 50 ha in size.

How do these reserve size classes compare with theoretical considerations for reserve size based on the autecology of species and ecosystem processes in the Cape Floristic Region?

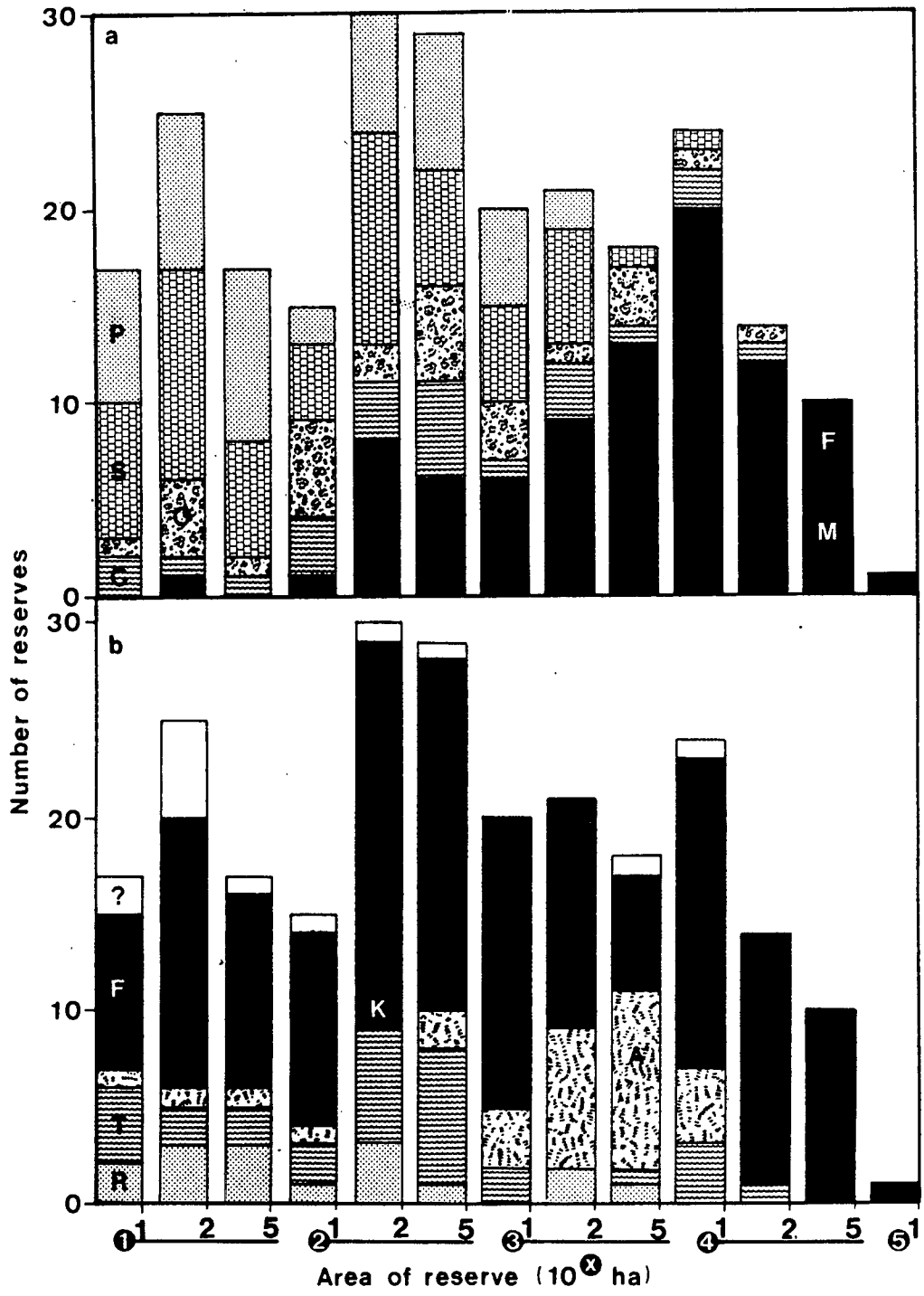

FIGURE 1.1.6. The frequency of reserve size classes in the Cape Floristic Region.
a) Categorized by owner: C = provincial nature reserves, F = State Forests, M = contractual reserves, O = other state reserves (National Botanical Institute, National Parks Board, South African Defence Force), P = private nature reserves and natural heritage sites, S = subsidized nature reserves.
b) Categorized by the dominant vegetation type within the reserve: A = afromontane forest, F = fynbos, K = karroid shrubland, R = renoster shrubland, T = thicket, ? = no data).
The abscissa is a logarithmic scale: white numerals refer to the exponent. Data from the Percy FitzPatrick Institute of African Ornithology data base (Siegfried 1989) and Cowan (1987).

Biogeographical considerations

An empirical study on the effects of island size on plant species richness has been undertaken in the relatively species-poor fynbos of the southern Cape Floristic Region (Bond et al 1988). Fynbos 'islands' surrounded by afromontane forest, supported significantly fewer species than mainland sites of the same area, with up to 75% extinction on the smaller islands. This island effect disappeared at about 600 ha. Species were apparently lost from islands due to a change in the disturbance regime, with smaller islands burning less frequently. This hypothesis was supported by the lack of resprouting and lower, shorter-lived species on islands. There was no evidence for a collapse of mutualisms, whether dispersal or pollinator, nor were dioecious species especially prone to extinction. There is, however, no basis for extrapolating these results to more species-rich areas of the Cape Floristic Region, due primarily to differences in the frequency of natural ignition events (Le Maitre and Midgley MS).

A study of fynbos on limestone islands within acid sand fynbos compared with equivalent sizes of fynbos on extensive limestone deposits, yielded minimum reserve sizes of only 4-15 ha (Cowling and Bond in press). Only local limestone endemics and limestone specialist shrubs (calcicoles), those arguably most in need of preservation, were vulnerable to extinction. Frequencies of dispersal and pollination syndromes, growth forms and height classes were unrelated to island size. Since the limestone islands are exposed to the same disturbance regimes as, and share pollinators and seed dispersers with, acid sand fynbos (Cowling and Bond in press), these minimum areas are only applicable to reserves in which disturbance (specifically fire) regimes are maintained, and which have access to pollinators and seed dispersal agents.

There appears to be a case for preserving very small patches (>4 ha) of vegetation, provided that the disturbance regimes are maintained. It is only in much larger reserves (ca 500 ha in the mountains of the southern Cape) that disturbance regimes are maintained naturally, so that all reserves less than 500 ha will invariably require management to maintain fire regimes and, thus, species richness.

Critical population size and habitat area: plants

The theory of minimum viable population size has emphasized the concept of a critical range of populations sizes below which demographic, genetic, and environmental stochasticity strongly reduces a population's chances of long-term survival (Gilpin and Soule 1986). The mean population size of several fynbos plant species is below 50 (Kruger 1977, seven species in the Proteaceae - Tansley 1988), with a few species only ever recorded as occurring in populations of fewer than 10 individuals (e.g. *Sorocephalus imbricatus*, *S. palustris*, *Mimetes stokoei* in the Proteaceae). Although seed bank sizes of these species are unknown, so that the species are not necessarily susceptible to inbreeding depression or loss of heterozygosity, the areas occupied by these species are consistent with the notion that preserving seed banks requires a far smaller area than for adult plants. Thus, the preservation of rare fynbos plant species could be undertaken, with appropriate (intensive and expensive) management, in several thousand pocket-handkerchief reserves each several hectares in size. Such reserves will probably result in the local extinction of more common species, which generally occur in extensive populations (Bond 1989), and sparse species, but should be adequate for preserving target rare species. However, the rarer species may be in the process of losing heterozygosity. Hence, data on the genetic status of rare species are required before any conclusions can be drawn.

Kruger's (1977: 83) statement '(where) populations are so small it would in principle be best to include the total populations in reserves

where possible' is a debatable viewpoint of little utility for determining minimum reserve size. Even where rare species tend to co-occur in rare habitats, these habitats often comprise small patches in the total landscape. Thus reserves as small as patch sizes may be feasible, provided that ecological processes shared between patches, such as fire regimes and water table dynamics, are maintained (Cowling and Bond in press).

Preserving higher trophic levels

Arguments based on the size of reserves to maintain minimum viable populations of large herbivores and carnivores have usually focussed on single reserves. Seldom have reserve networks been considered. Thus, Kruger's (1977) arguments assume that each reserve must maintain minimum viable populations, and consequently his minimum viable reserve sizes are very large. If the entire reserve network is taken as the unit, then the majority of reserves need only contain the minimum viable family unit, provided that adequate corridors exist to allow movement of non-territorial and immature individuals between nature reserves. Where -no corridors exist, each reserve designated for a particular species must contain a minimum viable population of those species.

The requirement for large reserve sizes does not mean, as argued by Kruger (1977), that the Protea Seedeater *Serinus leucopteris* would require a nature reserve of 1 000 ha as a minimum area for its survival (assuming a density of one pair of birds per 2 ha in its favoured habitat, under optimal fire management and a minimum viable population of 150 breeding pairs (Kruger 1977)). Presumably, 500 reserves each 2 ha in size would equally suffice, provided that the configuration of reserves could allow movements of Protea Seedeaters between reserves. Distances moved by Protea Seedeaters are unknown, but the species does not occur on the Cape Peninsula (Hockey et al 1989), a 28 000 ha mountain island of apparently suitable fynbos habitat, separated by 40 km of lowland from the nearest mountain. Since the Peninsula was connected by mountains to the 'mainland' 20 000 years ago (Dingle and Rogers 1972), it could perhaps be countered that Kruger's estimates are too low. The Sentinel Rock Thrush *Monticola explorator* and Victorin's Warbler *Bradypterus victorini* are similarly absent from the Cape Peninsula despite the apparent abundance of suitable habitat (Hockey et al 1989).

Because fynbos occurs on nutrient-poor soils, its carrying capacity for sustaining large herbivores is low (Cody et al 1983). Thus, ecologically balanced reserves (in which large herbivores and top predators typical of the vegetation can be preserved indefinitely without intervention) in fynbos should be very large. Fortunately the mountainous topography of the region which favoured the establishment of contractual reserves (for water production) allows movement of large mammals between core statutory reserves.

Mountain fynbos is considered so unsuitable for stock farming that official estimates of carrying capacity have not been made, although the carrying capacity of lowland fynbos of the west coast is 7.5 ha per small livestock unit (CJ Pienaar personal communication). Thus, preservation of the Cape Mountain Zebra (= 8.0 small livestock units (L Viljoen personal communication)) would require a minimum of 30 000 ha of fynbos vegetation to support a viable population of about 500 animals (ie in 100 single stallion herds with a mean of ca 5 animals (Smithers 1983)). However, the minimum reserve size (to support a minimum viable family unit) would be about 300 ha, provided individuals could move between reserves. It is difficult to establish whether the Mountain Zebra did, in fact, occur in fynbos historically. Two possibilities exist: either the Quagga *Equus quagga* occupied the renoster shrubland with the Mountain Zebra in fynbos; or alternatively, both species could have occurred in renoster shrubland, with the

Mountain Zebra being more efficient at retreating to the mountains when persecuted (Skead 1980). Since renoster shrubland in the mountains has double the carrying capacity (34.2 ha per zebra) of fynbos (CJ Pienaar personal communication), preservation of Cape Mountain Zebra should rather be emphasized in reserves containing this vegetation type. However, only ca 9 000 ha of mountain renoster shrubland are currently preserved (Cowan 1987). At present Cape Mountain Zebra preservation is centred in the Karoo mountains (Smithers 1986), with its higher carrying capacity of 10.2-34.2 ha per zebra (L Viljoen personal communication).

Data for Chacma Baboon *Papio ursinus* suggest an area relationship per troop in fynbos on the southern Cape Peninsula of $A = 40I + 80$, where A is area (in ha) and I is the number of individuals per troop (Davidge 1976). Recorded troop sizes in fynbos range from 6-85 (Davidge 1976), requiring from 320 to 3 500 ha per troop. Although these troops are largely confined to fynbos, they regularly consume shellfish from the seashore and large quantities of seeds from the alien *Acacia cyclops* (Hall 1963, Davidge 1976). This suggests that far larger ranges would be required for animals confined to pristine fynbos and that most troops probably occupy portions of other vegetation types.

Fynbos nature reserves aimed at maintaining viable populations of large mammals have been unsuccessful. The siting of the original Bontebok National Park in fynbos, at Bredasdorp, culminated in a decline in the numbers of Bontebok primarily due to nutrient deficiencies and concomitant disease (Barnard and Van Der Walt 1961, Van Rensburg 1975). Numbers only increased after the animals were translocated to a reserve containing renoster shrubland (Barnard and Van Der Walt 1961). Similarly, the 'big-game'-orientated management policy of the Cape of Good Hope Nature Reserve and Bontebok National Park, necessitated the provision of salt-licks and other practices incompatible with flora conservation; such as frequent burning to convert fynbos to grassland, bushcutting, the cultivation of alien pasture grasses, and the broadcast dispersal of copper to overcome the major mammal trace element-deficiency (Millar 1970, Van Rensburg 1975, Greyling and Huntley 1984, D. Clarke personal communication). Despite these efforts certain large mammal species have been unable to establish themselves or have become extinct in the reserves (Millar 1970, De Graaf et al 1976, Van Der Walt et al 1976a,b). Similarly, the lack of sufficient renoster shrubland (16% the area of the reserve (Cowan 1987)) in the Gamka Nature Reserve may be a contributory cause of the decline of the Cape Mountain Zebra from 25 in 1986 to 18 in 1990 (Smithers 1986, Percy FitzPatrick Institute of African Ornithology files: Ken Coetzee 17-12-90).

Grazing and browsing mammals tend to concentrate their foraging in burned areas of fynbos (Cody et al 1983) with a disproportionately high consumption of flowers and other reproductive parts (Rebelo 1987b). Whereas the densities of large mammals might perhaps be regulated by judicious culling and forced 'migration' in nature reserves, the same is not true of smaller herbivores, such as Rock Hyraxes *Procavia capensis*. This animal has been implicated in the lack of reproduction of plants in fynbos (Macdonald 1989). The only effective management of such animals is by preserving ecosystems which are large enough to support the top predators thought to be indigenous to fynbos, namely, Leopards *Panthera pardalis*, Caracals *Felix caracal*, and Black Eagles *Aquila verreauxii*.

The home ranges of Leopard in the Cape Floristic Region have been investigated for only two regions. In the Franshoek/Dutoitskloof district, home ranges were 38 800 ha for a male and 48 700 ha for a female, with a total range of 44 400 ha and 67 000 ha, respectively (Norton and Lawson 1984). These are among the largest home ranges recorded for Leopards outside of arid regions. By contrast, the home ranges of three male Leopards in fynbos in the Cedarberg

district were 4 950±1 500 ha (mean ± standard deviation, total range = 8 480±3 840 ha), an order of magnitude smaller (Norton and Henley 1987). Assuming the degree of territorial overlap is similar in the two districts, crude Leopard density is currently one per 1 100-8 000 ha, giving a total of between 450 and 1000 Leopards in fynbos in the Cape Floristic Region. Whether differences in density reflect carrying capacity or human interference is uncertain. Norton and Henley (1987) suggest that Leopard densities are higher in the Cedarberg, where Rock Hyraxes are the major component of the diet (Norton et al 1986), although a large proportion of legally-killed Leopards were from the south-western Cape (Stuart et al 1985). A 'safe zone' or 'open sanctuary' for Leopards of 450 000 ha was proposed as early as 1977 in the mountains of the Outeniqua and Kouga districts (Stuart et al 1985), and some Leopard conservation areas have been established by the Chief Directorate of Nature and Environmental Conservation (Hilton-Taylor and Le Roux 1989). However, the Outeniqua State Forests are heavily afforested and have not been ceded to the Chief Directorate of Nature and Environmental Conservation, so that the scheme may need to be reassessed. Perhaps the optimal preservation of Leopards should envisage fynbos as a sink area, with Cape Floristic Region reserves containing karroid and renoster shrubland, together with karroid shrubland on the escarpment to the north of the Cape Floristic Region, as suitable source areas.

Only a single Caracal home range, 6 500 ha for a young male in the Franshoek/Houwhoek district, has been determined (Norton and Lawson 1984). The data suggest that although territories do include fynbos, most activity occurs in neighbouring vegetation types. Excursions into fynbos were rare and associated with dispersal behaviour, during which the individual covered a total range of 89 500 ha in 18 months (Norton and Lawson 1984).

Estimates of Black Eagle densities are not available for fynbos. Vernon (in Macdonald and Gargett 1984) estimates their density at 1-3 birds per 10 000 ha for the entire Cape Province. Within the Cape Floristic Region, densities are estimated at between 9-28 breeding pairs per 1 000 000 ha, with a total of about 230 pairs (Boshoff and Vernon 1980). Since birds are persecuted as stock thieves (Siegfried 1963), carrying capacity in the Cape Floristic Region is almost certainly higher than 16 000 ha per pair (assuming that birds foraged only in fynbos in the mountains), and can presumably be preserved in a much smaller area within the Cape Floristic Region if their persecution in neighbouring, more productive, stockland is terminated.

Assuming that the total reserve system could maintain a minimum viable population with individuals moving between reserves, then a minimum fynbos reserve size to maintain a single pair of top predators would be 16 000 ha in the south-western and 2 200 ha in the north-western Cape Floristic Region. These figures could presumably be reduced if distances between reserves were sufficiently small to allow territories to be divided between reserves, or if renoster shrubland with its higher carrying capacity were included in the reserves.

Alternatively, should corridors not be suitable for Leopard or zebra movements, a reserve of between 100 000 and 1 000 000 ha would be required to preserve a minimum viable population of 50 pairs.

Fire management

Fynbos is a fire-maintained ecosystem (Van Wilgen et al MS). Historically, fire management has changed from the extensive use of fire to obtain pasturage, to total protection in the middle of this century (Kruger 1979). Thereafter, the occurrence of large uncontrollable fires and research indicating that certain species required fire, lead to the use of fire as a conservation and management tool (Kruger 1979, Boucher 1981b). Subsequent

research has focussed on season of burn and fire frequency (Van Wilgen 1987, Van Wilgen et al MS). Recently, coupled with the devolution of authority for state lands to local authorities, block burning was curtailed pending the outcome of certain court cases in which private property was damaged during 'controlled' burns.

The Directorate of Forestry divided reserves into management units (compartments), each burned about every 12 years (Kruger 1977). Since managers consider 500-1 500 ha as optimal-sized fire compartments, Kruger (1977) regarded 5 000 ha as the minimum reserve size required to 'maintain an even distribution of habitat age-classes'. The reasons for maintaining an even distribution of habitat age-classes are not given, but are probably in order to maintain resident populations of large mammals, nectarivores and seed-eating mammals and birds that might be confined to either only very young or mature vegetation. Historically, fires have occurred over large areas, often exceeding 10 000 ha in area (Kruger 1979). Large fires would have forced pollinators and predators to emigrate from the burned area, only recolonizing once flowering started. A guild of plants, comprising about 150 species, mostly species of the Proteaceae, Bruniaceae, and Asteraceae which may dominate fynbos, store seeds in the canopy (serotiny) until after a fire-perturbation (Le Maitre 1987, Le Maitre and Midgley MS). This has been proposed as a predator satiation strategy (Bond et al 1984). Under Kruger's scheme, where a compartment within the reserve is burned every year, high levels of seed- and seedling-predators may be maintained locally in the reserve, perhaps reducing recruitment of serotinous plant species. Because burns temporarily increase the carrying capacity of fynbos vegetation, the burning of one compartment per year is often used by reserve managers to maintain large mammals in fynbos, at the expense of plant species susceptible to grazing or short-rotation burns (Rebelo 1987a).

In short, optimal fire management practices do not reflect the large areas burned historically, and presumably prehistorically, and should not be used to speculate on reserve sizes. It can equally be argued that all reserves below a certain arbitrary size be treated as a single fire compartment. Since the length of compartment perimeters is where money is spent in prescribed burning operations (Kruger 1977), reserves of all sizes can be 'optimally' managed as a single compartment to decrease costs. To date, no research on the size of fires on the patch dynamics of fynbos landscapes has been undertaken (Van Wilgen 1987). If large fires are essential for reducing seed-predator numbers, it might be fortunate that managers are unable to suppress the extensive fires which occur periodically, despite current fire-control techniques (Kruger 1979, Van Wilgen 1987).

The role of corridors

The above discussion on optimal reserve sizes assumes that adequate corridors exist between reserves. However, virtually no data exist on the importance of corridors in the Cape Floristic Region.

Movement patterns of nectarivores are poorly known, but suggest that corridors may not be essential for nectar-feeding birds (Rebelo 1987c). For instance, Cape Sugarbirds *Promerops cafer* and Orangebreasted Sunbirds *Nectarinia violacea* occur in large numbers in lowland proteoid fynbos on the south coast during spring, but are largely absent during other periods (personal observations). Presumably they overwinter in the neighbouring Outeniqua mountains, which entails a movement of 20-40 km over nectar-barren habitat. Mist-netting of Sugarbirds in the south-western Cape indicates movements of over 30 km, both over nectariferous and nectar-barren habitats (Fraser et al 1989). Corridors do, however, appear necessary for the insect visitors to protea inflorescences. For example, insects are relatively scarce at 'Protea Heights' where the nearest natural protea stands are seven

kilometres away (JH Coetzee personal communication).

A large proportion of fynbos plant species have ant-dispersed propagules which seldom move more than a few metres from parent plants (Bond 1989, Cowling and Bond in press), so dispersal rates of these plant species along corridors is likely to be negligible. No data exist on the importance of corridors for plant population movements. Such data are essential as the only available land for preservation of fynbos in the greater Cape Town metropolitan area consists of corridors under powerline servitudes and in road reserves (McDowell et al in press).

The use of road verges as corridors, or even nature reserves, has proved viable in Australia (Saunders et al 1987, Van Der Breggen and Dawson 1989). Some 23 200 ha of the Cape Floristic Region is under tar macadam or gravel roads, with 50 800 ha of road reserve potentially available for preservation (0.6% of the Cape Floristic Region) (Macdonald 1989). Road reserves form a large component of the potential area available for the preservation lowland renoster shrubland. Unfortunately, there seems to be resistance to the idea in the Cape Floristic Region, with authorities favouring the maintenance of road verges as mowed grass parks (Department of Transport 1985, B Dawson personal communication). Within the greater Cape Town metropolitan area, the area of road reserve alongside National Roads (excluding the 8 ha N7-N1 interchange priority conservation site) alone amounts to more than 45 ha: a potential ten per cent increase in the area available for reserves (McDowell et al in press).

Preservation without reserves

Do we need additional reserves to preserve species diversity in the Cape Floristic Region? Two possible alternatives to a reserve network are preservation in Botanical Gardens and Zoos and preservation within multiple land-use systems such as agricultural land.

Ex situ preservation

Part of the National Botanical Institute's mission is to provide the facilities, knowledge and expertise necessary to ensure the conservation of the flora (National Botanical Institute 1990). Can preservation of plants be adequately undertaken within its botanical gardens and seed storage banks?

For many species of plants it is possible to store far larger quantities of seed than total number of adult plants alive in the wild. However, in natural populations plant gene banks comprise both adults and seed banks. Long-lived seed banks can store genes for several generations: fortunately, the dormant seeds of these species usually store well ex situ (Ashton 1987). Some fynbos and renoster shrubland plants have long-lived seed banks (see Boucher 1981b), but this is not always the case for both serotinous (Le Maitre 1987) and non-serotinous species (Pierce and Cowling 1991). In reality, it is seldom possible to acquire large numbers of seeds between the identification of the threat and the elimination of species.

An advantage of preserving species in ex situ seed banks is the small spatial requirements relative to that of preserving adult plants. However, seeds cannot be stored indefinitely. Unless the seeds can be returned to a natural area before they lose viability, artificial propagation must be undertaken to maintain the seed bank (Ashton 1987).

Furthermore, problems of cultivation, including seed germination, seedling establishment, watering, transplanting, flower induction, pollination and breeding systems, must be solved for each species before it can be adequately preserved. Although much research has been done in local botanical gardens, very little information has been published (National Botanical Institute 1990). Loss of genetic diversity can occur via the unintentional selection of phenotypes for protracted seed longevity, rapid germination, fast growth, resistance to horticultural pests, and the

selection of large-flowered or 'perfect' forms (Given 1987). This may result in populations with seed germination cues, pathogen resistance, predator-evasion mechanisms and flowering and growth phenologies maladapted to field conditions. Unfortunately, merely cultivating a species may result in skewed genetic representation by the differential survival of individual plants (Given 1987). These maladaptations may be sufficient to prevent the species from establishing. By contrast, the selection of strains that are purged of deleterious recessive genes may be an essential first step to preserving species prone to inbreeding depression (Vrijenhoek 1989). In addition, there is the problem of hybridization, not only with different species, but also with phenotypes adapted to different environments. Although asexual propagation can be used where hybridization is a problem, it can result in the accelerated loss of genetic diversity if selection of easily rooting or fast growing phenotypes occurs. Although ex situ seed banks and propagation are viable short-term options, their long-term prospects are poor. We do not even know how to adequately preserve important crop species (Conway 1989). As with animals (Gilpin and Soule 1986, Ralls et al 1986) 'captive' propagation should be a stop-gap measure, aimed at rescuing species by the rapid propagation and re-establishment in a natural habitat (Ledig 1986, Conway 1989). Not only is prolonged cultivation expensive, but even short-duration failures may negate years of preservation (Ashton 1987).

Box 1.1.6 For example, entire collections of plants have been lost when expertise left the Kirstenbosch National Botanical Gardens. Thus the Diminutive Powderpuff *Sorocephalus tenuifolius* (Proteaceae), comprised seven individuals in cultivation when it went extinct in the wild in 1985, which were transferred to Kirstenbosch (Hall and Veldhuis 1985). Although propagation attempts were made, all plants were lost when the horticulturalist in charge of the Proteaceae section left Kirstenbosch during 1987-8 (Anon 1988).

Preservation in non-reserve multiple-use areas

About 80 per cent of land in the Cape Floristic region is privately owned (McDowell 1986a). The ideal preservation system is one in which human activities are compatible with long-term preservation of biotic diversity.

The wildflower industry has championed its contribution to the preservation of fynbos by its commercial utilization of this resource in situ (Davis 1990). This has been advocated as an alternative to reserves, with productive utilization and land custodianship mooted as a strong force for resource conservation (Davis 1990). However, harsh harvesting techniques which drastically reduce plant seed banks (Greig 1984, Rebelo 1987b, Rebelo and Holmes 1988), coupled with lack of law enforcement, suggest that species may not be safely utilized, even in proclaimed mountain catchment areas and nature reserves. Recurrent pleas by the industry to invest in monospecific plantations of specific horticultural varieties to increase the standard of material produced, especially for the highly competitive overseas market (Anon 1990), suggests that there is no long-term conservation future for commercially-exploited fynbos (Davis 1990).

Advances in modern technology are resulting in the cultivation of agriculturally marginal lands which once harboured natural vegetation. Current legislation favours the conversion of marginal lands to agriculture as a tax-evasion strategy, and legislation to prevent the cultivation of virgin lands appears to be seldom enforced (McDowell 1986a).

Box 1.1.7 For example, the only population of the Diminutive Powderpuff was considered safe as its substratum was 'protected' by a metre-thick layer of sandstone overlying the fertile shales; heavy machinery solved the problem and replaced the habitat with an apple orchard (personal observation). Similarly, drip irrigation with nutrient solutions allows the establishment of orchards on nutrient-poor fynbos soils, and 'landscaping' allows the establishment of vineyards on steep slopes - habitats which appeared to require no protection 10 years ago.

Frequent burning of fynbos, at a cycle too short to allow regeneration of most plant species, promotes grass cover and is often utilized to provide extra grazing. This practice can be legally restricted only in contractual nature reserves and mountain catchment areas.

The preservation of the Cape Floristic Region outside reserves is thus uncertain. As economic incentives increase, so natural vegetation will be replaced by planted pastures in renoster shrubland and orchards of alien and indigenous plants in fynbos. Therefore, long-term preservation appears to require the legislation of contractual reserves as a minimum option.

Synthesis: options for preserving fynbos

Although most mountain districts have at least a single statutory reserve of sufficient size (>10 000 ha) to maintain top predators (Table 1.1.3, Figure 1.1.6a), only one sufficiently large fynbos reserve (De Hoop) exists in the lowlands. Since corridors for predators are unlikely on the lowlands it is vital, therefore, that the two proposed reserve networks (Dassenberg and Agulhas) in the Malmesbury and Bredasdorp districts (Jarman 1986) be acquired in toto for preservation within these districts to be ecologically viable.

With the above in mind it has been expedient to emphasize that very small reserves are adequate for the preservation of specific plant species, and, provided that corridors exist between nature reserves, very small reserves are also ecologically viable. This argument contrasts with historical considerations (Kruger 1977) maintaining that reserves should be as large as possible. Such arguments have led to a perception by current conservation planners that smaller reserves are not only too expensive to run, but also cannot achieve conservation objectives.

Relative costs per species or area do increase with smaller units of preservation. This is not merely a function of traditionally perceived management costs (eg fencing, transport, fire control and policing), but also the costs of maintaining ecological processes and the research required to accomplish this. Thus, very large reserves may have very low management requirements. Small reserves need to be managed to maintain populations and ecosystem processes. However, this can be done ad hoc as problems with individual species manifest themselves. Ex situ cultivation requires that seeds must be obtained, stored, and germinated and plants must be grown and propagated. More importantly, research into possible problems must be undertaken before any preservation can be effective. The costs of a species preservation programme increases by between 10- to 10 000-fold at each of these three levels of intervention (Woodruff 1989). As small reserves are likely to be very much cheaper to manage than ex situ cultivation programmes, they have an integral role in the preservation of the flora, especially in the short to medium term. This applies especially to the preservation of extremely localized plant species in agricultural areas.

Conservation research priorities in the Cape Floral Region should be centred on the effects of fragmentation, the role of corridors and the maintenance of natural disturbance regimes. Soule and Kohm (1989) emphasize the need for a coordinated programme of comparative research on populations, communities and ecosystems in relatively undisturbed and secure situations. Two such fynbos sites, where preliminary baseline information has been collected, exist. Research and monitoring in these areas should continue, and suitable sites

in other vegetation types should be identified. Although local Botanical Gardens are increasingly becoming involved in the preservation of plant species, the high numbers of threatened species and costs of ex situ cultivation require innovative approaches. A key area for research should be the use of devegetated roadside verges for establishing large 'ex situ populations' of locally endangered species. With an emphasis on multi-species stands, road verges, in addition to a corridor function, may also serve an educative and tourist role. Experience gained whilst revegetating road verges could lay the foundations for the potential use and acquisition of agricultural lands as future nature reserves.

LONG-TERM PROSPECTS

Aliens

Much fynbos is invaded by *Hakea sericea* (Proteaceae), *Pinus pinaster* (Pinaceae) and *Acacia longifolia* (Fabaceae) in the mountains and *A. cyclops* and *A. saligna* in the lowlands. Some 7 592 and 8 962 km^2 of mountain and lowland vegetation, respectively, are invaded by aliens, often forming monospecific stands (Macdonald and Richardson 1986, Richardson et al MS). *Hakea* and *Pinus* can be effectively controlled by felling all seed-producing plants a year before burning (Macdonald and Richardson 1986). In the past the Forestry Directorate of the Department of Environment Affairs was responsible for clearing infestations in the mountains. With the conservation section of that department now subsumed under the Chief Directorate of Nature and Environmental Conservation, future control will not be subsidized by the newly privatized afforested areas (Van Wilgen et al MS).

The introduction of a weevil *Erytenna consputa* for the biological control of *Hakea*, has greatly reduced seed production, thus reducing post-fire population sizes (Moran et al 1986). Similarly, the introduction of *Trichilogaster acaciaelongifoliae* should lower seed output and vegetative growth of *Acacia longifolia* (Moran et al 1986), and the fungus *Uromycladium tepperianum* should do the same for *A. saligna* (Kluge et al 1986). Indigenous agents have also begun impacting on aliens: eg *Zulubius acaciaphagus*, a bug, on seeds of *A. cyclops* (Holmes and Rebelo 1988); and, *Colletotrichum gloeosporioides*, a fungus, on stems of *H. sericea* (Kluge et al 1986). However, changes in management attitudes suggest that while integrated mechanical and biological control may be feasible in plantations and agricultural land, long-term control must be totally biological.

Furthermore, the preservation of aliens within statutory reserves must be considered if minimum viable populations of biological control and indigenous agents are to be maintained. This will become more important as the natural environment becomes more fragmented and reserves more insular.

Box 1.1.8 Alternative strategies, such as maintaining biological control agents in laboratory cultures or in plantations of alien plants, are exposed to the same problems as experienced by ex situ preservation of indigenous species. Such interventionist approaches may result in local 'boom and bust' population fluctuations of alien plants with the possible loss of indigenous plant species during boom phases.

Population growth and urbanization

The greater Cape Town metropolitan area currently contains about 2.2 million people (Anon 1986). Since the relaxation of legislation controlling the movement of black people, there has been a large influx of impoverished and poorly educated people from rural areas outside the Cape Floristic region. This will swell the population to 3.5 million people by the year 2000 and to 6.2 million people by 2020 (Anon 1986, Anon 1991). The rapidity of these changes is highlighted by the proposals for a False Bay Coastal Park in 1986 (Jarman 1986) having to be scrapped in 1987 as the region had been zoned and partly developed as a black

residential area in the interim (Burgers et al 1987).

The conservation implications of the increase in population size has not yet been addressed, nor have strategies been proposed to protect species diversity within the burgeoning metropolitan area.

With the increasing population, natural areas, including nature reserves, have become popular for recreation. Deterioration of footpaths, hiking trails and recreation sites due to increased use has been identified as a major problem (Moll and Campbell 1976). Research in high-altitude, nutrient-poor heathlands has shown them to be susceptible to trampling, taking many years to recover and leaving them open to invasion by weedy species (Liddle 1975, Bayfield 1979). Good guidelines, based on scientific principles for the establishment and maintenance of trails are needed (Moll and Campbell 1976, Moll et al 1978).

Global change

Any strategy for long-term preservation of nature should encompass evolutionary and biogeographical considerations. These are strongly influenced by climatic change. One 'worst-case scenario' speculates that as part of the 'greenhouse' phenomenon the Cape Floristic Region could become warmer and drier in the west and warmer and moister in the east (Rebelo and Siegfried 1990). Moreover, since the cyclone belt should move southwards, the entire region would receive rain in summer, rather than in winter as is the case at present.

Many typical fynbos species are sensitive to season of rainfall. Under summer rainfall, grasses invade oligotrophic soils and displace Restionaceae species. Restionaceae can be considered as slow-maturing, perennial herbs (Steiner 1988), so that their replacement by faster-growing grasses would facilitate short-rotation fires, instead of the much longer fire intervals under winter rainfall conditions (Van Wilgen et al MS). Fynbos can readily be converted to grassland in the eastern Cape by repeated burning (Trollope 1973, Gibbs Russell and Robinson 1981), suggesting that grasslands may expand westwards and replace fynbos taxa if the greenhouse phenomenon is fully realized.

Fynbos has probably been replaced by grassland, and vice versa, several times during the last two million years (Avery in press). This would have involved the westward dispersal of many fynbos taxa along the Langeberg-Outeniqua and Swartberg mountain ranges to high altitude refugia under conditions of predominantly summer rainfall. This might explain the higher richness of fynbos plant taxa in the mountains to the west of the region, assuming that the Cape Floristic Region was never entirely subject to a summer rainfall regime over its entire area (Cowling and Holmes MS). However, there are three major differences between the historical and the envisaged greenhouse climate changes: the future rate of change is projected to be far faster than in the past, and many plant species may not be able adapt to the new environmental pressures or disperse to potential refugia; the Cape Floristic Region is not completely preserved and past dispersal routes may thus no longer exist; and, the rapid changes in temperature on the land may be more-or-less uncoupled from those in the sea, so that coastal climate changes may be unlike that of the past.

Noda of naturally rare species in mountain fynbos (Figure 1.1.5), which may be Pleistocene refugia or speciation centres, are well preserved in nature reserves. The challenge to conservation biologists is to develop a reserve network for the lowlands of the Cape Floristic Region which can accommodate alterations of habitat and movements of species brought about by climatic change.

SYNTHESIS

Although 19 per cent of the Cape Floristic Region is preserved in statutory, private and contractual nature reserves, by far the majority of this area (96%) comprises fynbos in the mountains. Only 1.5 per cent of extant renoster shrubland, amounting to 0.6 per cent of the original extent of the vegetation type, is preserved. Similarly, only three per cent of the original extent of fynbos on the lowlands is preserved. Despite recognition of the need for preserving lowland areas since the 1970s, the prioritization of available lowland areas in 1986, and the high ranking of the lowlands of the Cape Floristic Region on a national basis, little lowland has been added to the reserve network over the past decade. This neglect has been attributed to the lack of large mammal diversity (Greyling and Huntley 1984), but the cost of land with high agricultural potential is also a major obstacle (McDowell 1986a). Contractual national parks currently appear to be the most successful strategy in acquiring preserves for vegetation types on nutrient-poor soils. The problem with renoster shrubland appears intractable, even appealing schemes for reintroducing the large mammals (eg Black Rhinoceros *Diceros bicornis*) would not overcome the high costs of acquiring suitable land.

The minimum reserve size for preserving minimum viable populations of higher trophic level herbivores and carnivores, appears to be about 10^5-10^6ha. Reserves of this size class occur in most mountain centres of endemicity, but few occur in the lowlands. Contrary to current management perceptions, reserves as small as 5 ha would be able to preserve species of plants provided that ecosystem processes and alien plants were adequately managed. Owing to the high numbers of threatened species, ex situ preservation is only feasible for a small proportion of species. Seed banking may offer a better solution, but large numbers of seeds may not be available from threatened populations. A strategy employing the cultivation of threatened species in suitable road verges to obtain plants and seeds for distribution and storage may be a possible answer.

The existing reserve network appears to be comprehensive for fynbos of the mountains, although centres of endemism to the northwest and arid interior are poorly preserved. By contrast the lowlands are very poorly preserved. With 15.1 Red Data Book plant species in the lowlands of the greater Cape Town metropolitan area and a further 171 Red Data Book plant species on Table Mountain in the heart of Cape Town, this area must rank as the top priority area for conservation action on the subcontinent. With current rates of urbanization and projected population growth, the future of threatened species within the region appears bleak.

Long-term prospects for the preservation of lowland vegetation in the Cape Floristic Region will be determined primarily by how the rapid human population growth rate in the greater Cape Town region is managed. Continued funding for the control of alien plant species is also required in the short-term.

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Part 2. Causes of Rarity

2.1.

The distribution and abundance of Red Data Book species in the Cape Floristic Region:

threats, priorities and target species.

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THE DISTRIBUTION AND ABUNDANCE OF RED DATA BOOK SPECIES IN THE CAPE FLORISTIC REGION:

THREATS, PRIORITIES AND TARGET SPECIES

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SUMMARY

The Cape Floristic Region (CFR) contains a disproportionate number of southern Africa's Red Data Book plants (70%), freshwater fish (57%), amphibians (43%), butterflies (38%), and reptiles (35%), relative to the small area (4%) of the subcontinent which it occupies. With the exception of reptiles, the vast majority of these species are endemic to the CFR, occurring mainly in Mountain and Lowland Fynbos vegetation. Among the threats to the continued survival of these species, agriculture and alien invasive plants rank the highest overall, although scavenging birds and large mammals have been largely hunted and poisoned to extinction within the CFR. An active reintroduction of these large mammals from outside the CFR has been the dominant strategy of local conservation agencies. The geographical distribution of threatened species is not related to the extent to which vegetation types have been transformed. Thus Renoster Shrubland which has been reduced to 6 per cent of its original lowland extent contains few Red Data Book taxa relative to Fynbos. By far the largest concentration of Red Data Book species of plants, butterflies, reptiles and amphibians occurs in the greater Cape Town metropolitan area. With 15.1 Red Data Book plant species per km^2, this area must rank as one of the most urgent conservation priorities in the world.

INTRODUCTION

The Cape Floristic Region (CFR) occupies some 90 000 km^2 at the southern tip of Africa. With 6800 plant species, of which 68 per cent are endemic (Bond and Goldblatt 1984), it ranks as one of the world's six floristic kingdoms (Taktajan 1986). In terms of local plant species richness, some centres of endemism in the CFR rank with the richest centres in tropical rain forests (Cowling *et al.* in press). However, unlike most rain forest centres of plant endemism, the CFR does not seem to have a similarly high richness and endemism of animal taxa. Furthermore, the large mammals and scavenging raptors were largely eliminated from the CFR during the 18th century. Consequently, conservation strategies in the CFR have lacked the "large and hairy" and "cute and cuddly" emphasis characteristic of conservation programmes elsewhere in Africa (Ferrar 1989).

The CFR has been, and is being, extensively transformed by pastoral, agricultural and urban development and alien plant encroachment (Jarman 1986, Macdonald and Richardson 1986, Rebelo in press). In the lowlands of the western Cape only 6 per cent of Renosterveld and 14 per cent of Fynbos are currently untransformed by these agents (Boucher 1981).

A holistic view, integrating patterns of threats to different species with areas containing high numbers of threatened species and the identification of suitable "target" species would greatly enhance conservation strategies in the CFR. Specifically I ask:

- Which taxa are threatened in the CFR and are they representative of those of the subcontinent?;
- In which geographical regions of the CFR are Red Data Book species concentrated and how does this pattern vary among taxa?;
- How do these patterns vary among the vegetation types within the CFR, given that vegetation types form the focus of conservation assessments and prioritization within the region?;
- What threats are responsible for the decline and extinction of species in the CFR, and how do these differ among taxa?; and,
- How have the above patterns influenced the conservation strategies adopted within the region?

METHODS

Taxa threatened

Red Data Book species of plants (Hall *et al.* 1980, Hall and Veldhuis 1985), butterflies (Henning and Henning 1989), fish (Skelton 1987), reptiles and amphibians (Branch 1988a), breeding birds (Brooke 1984) and mammals (Smithers 1983) were categorized as occurring either in the CFR (Figure 2.1.1), the remainder of the South Africa, or both. Peripheral species (those relatively common elsewhere in Africa) were excluded from Red Data Book lists for the remainder of South Africa. Species were categorized as threatened (by human activities: extinct, endangered or vulnerable), naturally rare (rare, critically rare (Hall and Veldhuis 1985), and restricted (Branch 1988a)), and those for which there is insufficient data (indeterminate or uncertain). Total species lists for southern Africa and the CFR were also compiled (see Tables 1-7 for references). These data were used to test the null hypothesis that the distribution of Red Data Book species should mirror both the total species and endemic species richness for the CFR and South Africa, respectively. Taxa especially susceptible to decreasing populations through human activities should be over-represented in Red Data Book lists.

Areas with concentrations of rare species

The historical distribution ranges of Red Data Book species of plants, butterflies, reptiles, amphibians, and fish were mapped on a quarter-degree grid system and species richness per degree-square was determined. It was not feasible to map the distribution ranges of species by quarter-degrees for Red Data Book mammals and birds as the historical distribution ranges are not known with sufficient precision.

Habitat ranges

For each group, species were categorized by which habitat they occurred in, using vegetation type categories defined by Moll and Bossi (1984) and plant biogeographic region (Weimarck 1941). Although habitat requirements are usually given in the Red Data Book species accounts, these proved inadequate. Furthermore, even though a preliminary analysis by vegetation type had been undertaken for plant data (Hall and Veldhuis 1985), this was apparently determined from distribution data at a quarter-degree scale. Consequently, these data may have a high degree of error. I made no attempt to modify any obvious errors as my knowledge of vegetation type requirements is largely confined to the Proteaceae. For butterflies (Henning and Henning 1989), habitat descriptions often refer

to vegetation and some food plants, but these were usually inadequate: confusion between vegetation types (Fynbos, Karoo, Thicket and Renoster Shrubland) and plants (references to 'grasses' in Fynbos vegetation, when probably Restionaceae are implied) were apparent. In addition, it is possible that butterfly male territories, adult- and larval-feeding sites may occur in different vegetation types: this could not be ascertained from the accounts. Thus habitat distributions for butterflies (and amphibians and reptiles) were based largely on dominant vegetation types present (Moll and Bossi 1984) at recorded localities. Where ambiguities were present, all probable vegetation types present at all current and historical sites were recorded. In the case of fish, the vegetation types through which the occupied portion of the river flows were used, ignoring any sediment translocation downstream which might modify the substratum.

Some data on historical distributions of mammals are available (Skead 1980), but seldom allow frequented vegetation types to be determined. I have therefore assumed that all large mammals which were historically absent from the Cape Peninsula (Skead 1980) tended to avoid Mountain Fynbos, and that all large herbivores were largely confined to Renoster Shrubland, Thicket and Karoo, and perhaps to a lesser extent West Coast Lowland Fynbos during spring, as argued by Skead (1980). Although very good distributional data exist for birds, habitat requirements for CFR birds are particularly poorly recorded: only feeding range was categorized as habitat.

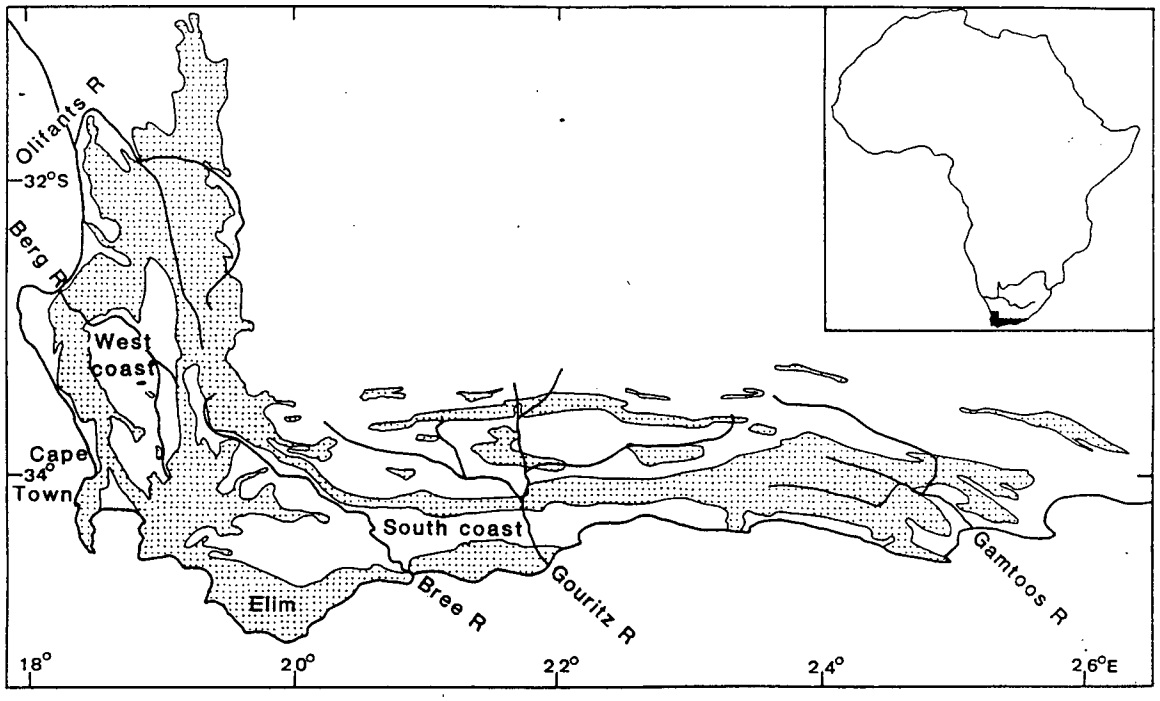

Fig. 2.1.1. The location of the Cape Floristic Region showing the distribution of Fynbos (shaded) and Renoster Shrubland (West coast, South Coast) vegetation and the location of the major river systems.

For mammals the distribution by vegetation types for each species was combined with mass data (from Smithers 1986) to determine the dispersion of mass classes within extinct, threatened and non-threatened species. Where mass data were not available, mass was extrapolated from related species based on body measurements. Geographic variation in mass was ignored, and the geographically closest population was selected where regional variation in mass was provided in Smithers (1986).

Types of rarity

Although Red Data Book species are often considered as 'rare', this typification masks the parameters associated with rarity. Based on their historical distribution ranges, species were categorized as:

- localized (confined to an area of less than five quarter-degree grid squares ($\pm 3\,000$ km^2) (= Restricted *sensu* Branch 1988a));
- sparse (occurring in many disjunct, small populations, or at low densities, over a wide area, with the distribution pattern unlikely to be the result of low collecting intensity); or,
- common (greater than $\pm 3\,000$ km^2 in areal extent, populations probably large and widespread).

This classification ignores total population sizes, but such data are not available, except for larger mammal and bird species. Furthermore, such available data do not reflect historical population sizes (Macdonald 1989).

Threats

Threats were totalled for all species for which threats were listed in the Red Data Books as causing, or possibly causing, a decrease in numbers: only in the case of plants were data consistently lacking. All mammal species over 50 kg which were extinct in the CFR prior to 1800 were considered to have been hunted to extinction (Skead 1980), rather than impacted primarily by stockfarming, agriculture or vegetation transformations (see discussion). For each taxon, the threats were scaled by dividing the totals per threat by the total for the largest threat and multiplying by 10. These scores were then totalled to provide an overall rank of threat. Some inconsistencies were noted: 'hybridization' was not recorded as a threat to plants, 'collecting' was dismissed as a threat to butterflies and 'genetic decline' was applied to most plant species with small adult populations.

RESULTS

Taxa threatened

The representation of plant families between the CFR and the rest of South Africa was region-specific ($X^2 > 1\,000$, $P < 0.001$, $df = 15$) (Table 2.1.1). Ten of the sixteen families included in the analysis exceeded the overall significance value for the Chi-squared test (*i.e.* $P = 0.05$: $X^2 = 26.3$) - the exceptions being the Asteraceae, Cyperaceae, Fabaceae, Orchidaceae, Oxalidaceae, and Scrophulariaceae. The Ericaceae, Campanulaceae, Iridaceae, Proteaceae, Restionaceae, and Rutaceae were over-represented in the CFR and the Asclepiadaceae, Euphorbiaceae, Mesembryanthemaceae and Poaceae under-represented in the CFR (Table 2.1.1). These results concord with the family composition of the Fynbos Biome (Gibbs Russell 1987).

Likewise, in the CFR, the frequency of endemic species among families differs significantly from that expected from total species richness ($X^2 > 145$, $P < 0.001$, $df = 15$). Values exceeding 20% of the significance value ($P = 0.05$, $X^2 = 26.3$) occurred in five families with too few endemics (Asclepiadaceae, Asteraceae, Euphorbiaceae, Poaceae, and Scrophulariaceae) and one with too many (Ericaceae) (Table 2.1.1). Analysis ofthe 10 most species-rich families in the CFR yielded similar patterns ($P < 0.05$, $X^2 = 16.9$, $df = 9$).

Table 2.1.1
Status of Red Data Book species and subspecies among families of Angiosperms in South Africa (RSA) and the Cape Floristic Region (CFR). Listed are the top ten families, by species richness, in each of southern Africa (sAf: Botswana, Lesotho, Namibia, South Africa (incl. the independent states), Swaziland: Gibbs Russell 1985) and the CFR (Bond and Goldblatt 1984), and the ten families with the most rare species in the CFR (Hall and Veldhuis 1985). Endemic species (End) to the CFR are from Bond and Goldblatt (1984), and Red Data Book species and subspecies for RSA excluding the CFR are from Hall *et al.* (1980). X = extinct; T = threatened (endangered or vulnerable); R = naturally rare; I = indeterminate or unknown.

	All species			Red Data Book taxa										
	sAf	CFR	CFR	Non-CFR					CFR					Shared
Family	Total	Total	End	X	T	R	I	Tot	X	T	R	I	Tot	
Asteraceae	2116	986	608	1	1	6	33	**41**	2	11	40	113	**166**	14
Ericaceae	984	688	666				1	**1**	5	26	48	59	**138**	0
Mesembry.	2408	660	507		5	4	31	**40**	1	11	10	34	**56**	7
Fabaceae	1540	644	525		1	21	5	**27**	1	9	21	79	**110**	1
Iridaceae	858	612	485		1	41	30	**72**	5	46	90	101	**242**	12
Proteaceae	366	320	306			6	2	**8**	3	62	58	8	**131**	1
Restionaceae	282	310	290			2	0	**2**	1	21	20	12	**55**	0
Scrophulariceae	543	310	160		2	1	10	**13**		2	3	30	**35**	3
Rutaceae	291	259	242			3	0	**3**	2	20	52	29	**103**	1
Campanulaceae	256	222	157			1	9	**10**		1	3	70	**74**	1
Orchidaceae	439	206	124		5	11	56	**72**		15	24	19	**58**	3
Cyperaceae	464	203	124					**0**			1	14	**15**	0
Poaceae	783	181	76		1	0	6	**7**		1	0	8	**9**	0
Oxalidaceae	195	129	90			3	8	**11**		3	5	42	**50**	2
Asclepiadaceae	769	125	35	1	10	14	31	**56**	1	9	12	29	**51**	10
Euphorbiaceae	461	97	38		6	11	10	**27**		5	2	9	**16**	2
Subtotal	12755	5952	4433	2	32	124	232	**390**	21	242	389	656	**1309**	57
TOTAL [1,2]	20370	8600	5865	4	71	257	339	**667**	29	282	420	704	**1435**	69
Total CFR [3]									26	255	389	656	1326	?

Notes:
[1] Other extinct species in the CFR belong to the Bruniaceae (3 spp), Crassulaceae (2), and one each in the Amaryllidaceae, Hyacinthaceae and Malvaceae.
Other CFR families with more than two threatened species include: Amaryllidaceae (13), Hyacinthaceae (7), Penaeaceae* (4), Bruniaceae* (3), and Polygalaceae (3). * = Families endemic (>95% species) to the CFR.
[2] All data based on Appendix 1 in Hall and Veldhuis (1985), where this differs from their Appendix 3, but with *Elegia fastigiata* (see Appendix 2 - Hall and Veldhuis (*loc. cit.*)) included as extinct.
[3] Total figures for Red Data Book species listed for the CFR in Appendix 3 of Hall and Veldhuis (1985): these exclude the Worcester and Little Karoo. The concordance between rare and indeterminate categories between the subtotal and total is incidental.

For the 10 richest CFR families, Red Data Book plant species richness differs significantly from that expected from total species richness ($X^2 > 200$, $P < 0.001$, df = 9): five families each almost exceeded the significance for the entire test ($P = 0.05$, $X^2 = 16.9$): Red Data Book species were under-represented in the Mesembryanthemaceae and Scrophulariaceae and over-represented in the Iridaceae, Proteaceae and Rutaceae (Table 2.1.1). Red Data Book plant species richness is significantly different from endemic species richness for the top 10 families in the CFR ($X^2 > 170$, $P < 0.001$, df = 9) - three families exceeded the significance for the entire test ($P = 0.05$, $X^2 = 16.9$): Red Data Book species were under-represented in the Mesembryanthemaceae and over-represented in the Iridaceae and Proteaceae; the Campanulaceae and Rutaceae

were also strongly over-represented (with values greater than 12.0) (Table 2.1.1).

Threatened (including extinct) plant species in the CFR (Table 2.1.1) are over-represented (value exceeding significance limits for test: P = 0.05, X^2 = 16.9, df = 9) in the Proteaceae relative to total Red Data Book species, and in the Iridaceae and Proteaceae relative to both endemic and total species. Similarly, the Asteraceae are under-represented relative to total species. Species marginally over-represented (value greater than 10.0 in the X^2) are the Campanulaceae relative to Red Data Book species and the Fabaceae relative to total species in the CFR.

The representation of butterfly families was strongly dependent on region (X^2 = 38, df = 8, P < 0.001), with the Lycaenidae over-represented and the Acreidae, Hesperiidae and Nymphalidae under-represented in the CFR (Table 2.1.2). Endemism in butterfly families was independent of the richness of endemic species in the CFR (X^2 = 15, df = 5, P < 0.05), with the Lycaenidae containing a higher, and the Nymphalidae and Pieridae a lower, than expected level of endemism. Similarly, the Lycaenidae contribute overwhelmingly (96%) to the incidence of Red Data Book species in the CFR. This dominance of the CFR by Lycaenidae is similar to the rest of South Africa, but other families (Hesperiidae and families not well represented in the CFR) comprise one third of the Red Data Book species in South Africa outside the CFR. Within the CFR all six threatened species belong to the Lycaenidae and no butterfly species is listed as extinct (Table 2.1.2), although *Lepidochrysops methymna dicksoni* has not been seen for 30 years, *Chrysoritis cottrelli* for 12 years, and *Argyrocupha malagrida malagrida* for 'a few' years.

Table 2.1.2
Status of Red Data Book species and subspecies among families of Butterflies (Lepidoptera: Rhopalocera) in South Africa and the Cape Floristic Region (Henning and Henning 1989). The old concept of Nymphalidae has been retained. Species totals for southern Africa (south of Angola and Zambezi River) and the CFR and CFR endemics are from Dickson and Kroon (1978). Headings as in Table 2.1.1.

	All species			Red Data Book taxa										Shared
				Non-CFR					CFR					
Family	sAf Total	CFR Total	CFR End	X	T	R	I	Tot	X	T	R	I	Tot	
Danaidae	7	2	0					**0**					**0**	-
Satyridae	78	23	7			6	3	**9**			1		**1**	0
Acraeidae	46	3	0				3	**3**					**0**	-
Charaxidae	37	5	1					**0**					**0**	-
Nymphalidae	68	10	0			4	2	**6**					**0**	-
Libytheidae	1	0	-					**0**					**-**	-
Lycaenidae	352	143	59	2	3	38	14	**57**		6	37	9	**52**	3
Pieridae	53	20	0			2		**2**					**0**	-
Papilionidae	17	3	0				1	**1**					**0**	-
Hesperiidae	123	25	5			6	7	**13**			1		**1**	0
TOTAL	782	234	72	2	3	56	30	**91**	0	6	39	9	**54**	3

Table 2.1.3
Status of Red Data Book species among orders of Mammalia (excluding marine Cetaceae and Pinnipedia) in South Africa and the Cape Floristic Region (Skead 1980, Smithers 1986, Rookmaaker 1989). Species totals for southern Africa (south of Angola and Zambezi River) and the CFR and CFR endemics are from (Smithers 1983). Headings as in Table 2.1.1.

	All species			Red Data Book taxa										
	sAf	CFR	CFR	Non-CFR					CFR					Shared
Order	Total	Total	End	X	T	R	I	Tot	X[1]	T[2]	R	I	Tot	
Insectivora	39	15	3		2	4	9	**15**			1	4	**5**	2
Chiroptera [3]	74	20	0				26	**26**				3	**3**	2
Primates	7	2	0			1		**1**					**0**	-
Philodota	1	0	-		1			**1**					**-**	-
Lagomorpha	7	3	0		1			**1**					**0**	-
Rodentia	78	33	4		2	4	6	**12**		1	1		**2**	2
Carnivora	37	26	0		3	9		**12**	4	3	4		**11**	11
Proboscidea	1	1	0					**0**		1			**1**	1
Hyracoidea	4	2	0			1		**1**				1	**1**	1
Tubulidentata	1	1	0		1			**1**		1			**1**	1
Perissodactyla	5	3	0	1	2			**3**	2	1			**3**	3
Artiodactyla	41	21	3	1	4	5		**10**	8	0	2		**10**	8
TOTAL	295	127	10	2	16	24	41	**83**	14	7	8	8	**37**	32

Notes: (* Reintroduced to the CFR; $ endemic; # globally extinct)

[1] Extinct:
Carnivora: *Crocuta crocuta* (60kg), *Hyaena brunnae* (45), *Lycaon pictus* (27), *Panthera leo* (200);
Perissodactyla: *Diceros bicornos* (860), *Equus quagga* (240)#;
Artiodactyla: *Alcelaphus buselaphus* (130)*, *Hippopatamus amphibius* (1 400)*, *Hippotragus leucomelas* (200)$#, *Oryx gazella* (230)*, *Redunca arundicum* (45), *Ourebia ourebi* (14) *Syncerus cafer* (780)*, *Taurotragus oryx* (600)*.

[2] Threatened:
Rodentia: *Mystromys albicaudatis* (0.09);
Carnivora: *Felis lybica* (5), *F. serval* (10), *Mellivora capensis* (12);
Misc.: *Loxodonta africana* (5 000); *Oryteropus afer* (52); *Equus zebra* (240).

[3] Only one species of bat is a non-breeding migrant to the subcontinent: it has been included in the totals.

The representation of families and orders of mammals, birds, reptiles, amphibians, and fishes was independent of region, *i.e.* not significantly different (X^2, $P > 0.05$) between southern Africa excluding the CFR and the CFR.

Apart from the endemic Bontebok *Damaliscus dorcas dorcas*, Bluebuck *Hippotragus leucomelas*, and Grysbok *Raphicerus melanotis* (Artiodactyla), three species of the Insectivora and four of the Rodentia comprise the total complement of mammal species endemic to the CFR. The two larger endemic ungulates were confined to Renoster Shrubland and the smallest to Fynbos. An endemic gerbil and fossorial molerat were confined to Lowland Fynbos and Thicket vegetation, the other two endemic rodents being generalists. One endemic shrew species occurs on the Fynbos/Forest ecotone, whereas the two endemic moles occur in Lowland Fynbos and Thicket vegetation. Rodentia, Insectivora and Chiroptera are under-represented among Red Data Book species relative to their abundance in the CFR: Red Data Book mammal species are dominated by species larger than 50 kg (73%: Table 2.1.3).

Mammals contain the highest proportion of extinct species (11%) of all the taxa in the CFR. Of the 16 mammal species recorded

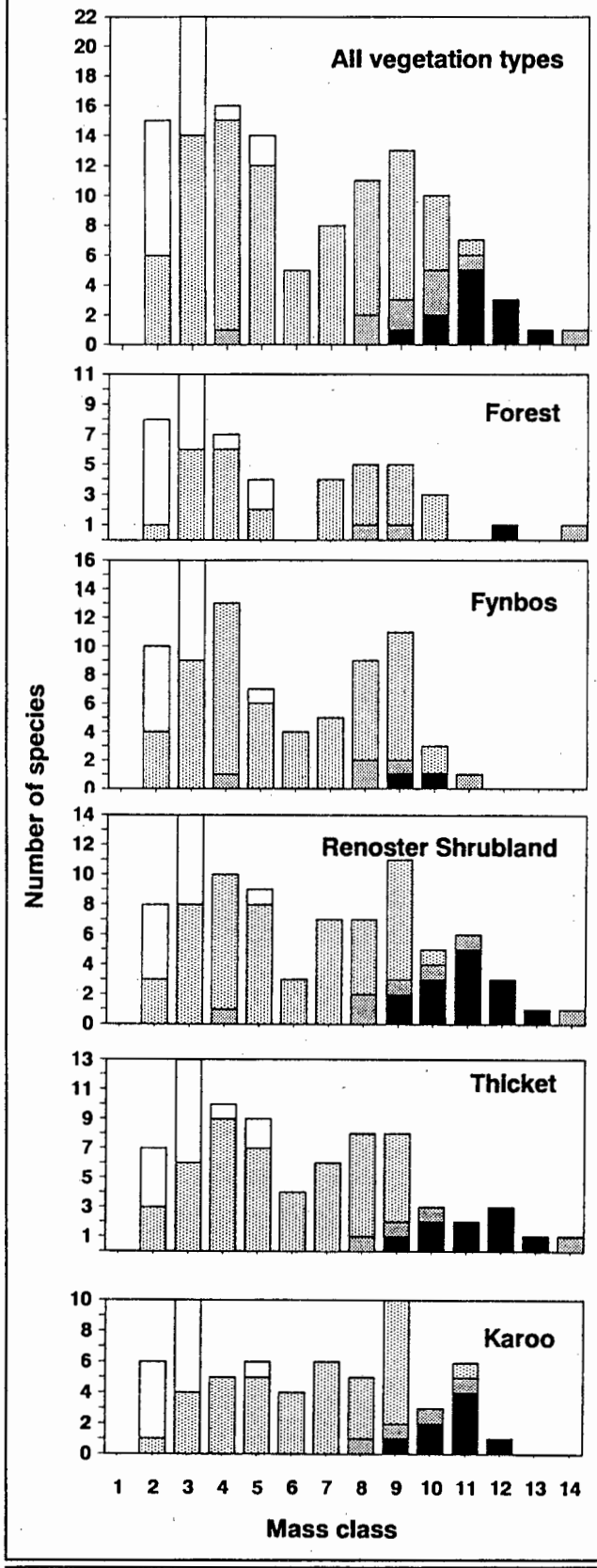

Fig. 2.1.2. The frequency composition of extinct (solid), threatened (dark shading), stable non-flying (light shading) and stable flying (= Chiroptera, unshaded) mammals by weight class* in the major vegetation types of the Cape Floristic Region. * (1) <3g, 3-10, 11-30, 31-100, 101-309, 310g-1kg, 1-3, 3-10, 11-30, (10) 31-100, 101-309, 310-10^3, 1001-3099, >3100kg)

historically that exceeded 50 kg in mass, 10 (63%) were hunted to extinction: two of these (Bluebuck and Quagga *Equus quagga*) are extinct globally. Four of these have been reintroduced into reserves in the CFR from elsewhere on the subcontinent (Table 2.1.3). A further three species over 50 kg in mass are in the threatened category, and the Bontebok is no longer threatened (since mid-20th century), so that 88 per cent of mammal species larger than 50 kg in mass have been impacted by human activities in the CFR. Only the bushpig *Potamochoerus porcus* and Kudu *Tragelaphus strepsiceros*, among mammals larger than 50 kg in mass, have not been adversely impacted by human activities in the CFR, the latter persisting even under heavy hunting pressure within its historical distribution range (Little Karoo) (Smithers 1983). Only four of the 14 mammal species (29%) exterminated from within the CFR were less than 50 kg in mass: two were carnivores and two were grazing ungulates (Table 2.1.3). Carnivora feature strongly among the threatened and naturally rare (sparse, not localized) species in the CFR, because of low densities and several hundred years of persecution by stock farmers (Table 2.1.3).

All mammals greater than 300 kg are threatened or extinct in the CFR (Figure 2.1.2). Other than the elephant *Loxodonta africana*, which survives in the CFR as three individuals (Smithers 1986), all mammals over one metric ton are extinct. Only a single species, the

Reedbuck *Redunca arundinum*, has gone extinct in Fynbos but this species was probably more common in Renoster Shrubland (Smithers 1986). Extinctions are most marked in Karoo, Renoster Shrubland and Thicket vegetation, which supported the largest mammals (Figure 2.1.2). The only mammal less than 5 kg that has had its distribution range reduced is the White-tailed Mouse *Mystromys albicaudatus*, which occurred in Fynbos and Renoster Shrubland (Smithers 1983).

Birds have the lowest levels of endemism (2.1%) of all taxa in the CFR (Table 2.1.4). Six Passerine species - two nectar-feeders, two granivores and two insectivores (all largely confined to Fynbos vegetation) - are endemic to the CFR, reflecting the preponderance of passerine species in the region. Two near-endemic species, the Cape Francolin *Francolinus capensis* (Galliformes, an omnivore in Thicket) and Cape Bulbul *Pycnonotus capensis* (Passeriformes: a frugivore in Thicket) were excluded as they extend along the west coast well north of the CFR.

Red Data Book bird species are strongly biased to birds of prey (Falconiformes) and cranes/bustards (Gruiformes) - passerines are under-represented (Table 2.1.4). Four bird species are extinct in the CFR: two vultures, a crane and a bittern. A further seven species, mainly Falconiformes and Gruiformes, are threatened - the majority of these are threatened throughout South Africa.

Table 2.1.4
Status of Red Data Book species among orders of Birds (Aves: excluding non-breeding birds and marine Sphenisciformes and Procellariformes) in South Africa and the Cape Floristic Region (Brooke 1984). Species totals for southern Africa (south of Angola and Zambezi River) and the CFR and CFR endemics are from Maclean (1989). Headings as in Table 2.1.1.

	All species			Red Data Book taxa										
	sAf	CFR	CFR	Non-CFR					CFR					Shared
Family	Total	Total	End	X	T	R	I	Tot	X[1]	T[2]	R	I	Tot	
Struthionif.[3]	1	1	0					**0**				1	**1**	1
Pelecaniformes	5	4	0			2		**2**			1		**1**	1
Ciconiiformes	32	16	0		1	1		**2**	1		1		**2**	2
Phoenicopterif.	2	2	0				2	**2**				2	**2**	2
Falconiformes	53	22	0		5	3	2	**10**	2	3	1		**6**	6
Gruiformes	31	15	0		4	2	1	**7**	1	3	1	2	**7**	7
Charadriiformes	26	13	0	1				**1**					**0**	-
Psittaciformes	8	0	-		1			**1**					**-**	-
Strigiformes	12	5	0		1	1	1	**3**		1			**1**	1
Coraciiformes	17	2	0		1		1	**2**					**0**	-
Piciformes	26	11	0			1		**1**					**0**	-
Passeriformes	360	137	6	1	6	3	8	**18**				1	**1**	1
Misc.	121	60	0					**0**					**0**	-
TOTAL	694	288	6	2	19	13	15	**49**	4	7	4	6	**21**	21

Notes:
[1] Extinct: *Botaurus stellaris, Gypaetus barbatus, Neophron percnopterus, Grus carunculata*
[2] Threatened: *Torgos tracheliotus, Polemaetus bellicosus, Gyps coprotheres, Turnix hottentotta, Neotis denhami, N. ludwigii, Tyto capensis*
[3] See text for problems with the status of the Ostrich *Struthio camelus australis*.

The status of the Ostrich *Struthio camelus australis*, the only bird exceeding 50 kg in the CFR, presents a problem of categorization. Despite some farmers maintaining tame ostriches as early as 1775, the species was apparently regularly hunted to the extent that a special proclamation was issued in 1822 to check its destruction (Smit 1963). Sufficient birds obviously remained during the 1850s, when domestication for the feather industry commenced. These birds were hybridized with a few imported males of *Struthio camelus camelus* from North Africa and *Struthio camelus syriacus* from Syria during the latter half of the nineteenth century in order to improve feather quality. Considerable selection for superior strains was undertaken at the turn of the century, when a studbook was maintained and hybrid stock was keenly sought after. During the slump of 1914 to 1930 the ostrich population decreased dramatically from almost 800 000 birds to 32 000; this period was characterized by intense culling of 'inferior' strains (Smit 1963). Today free-range birds are frequent on farms in the CFR (Hockey *et al.* 1989), although it is uncertain whether these are remnants of the local race or were obtained from domesticated stock: certainly a few show features indicative of hybridization (R.K. Brooke pers. comm.). Therefore the status of the Ostrich in the CFR might be variously considered, depending on interpretation of definitions, as extinct in the wild, threatened due to hybridization with hybrid domestic stock, or, due to the probable high proportion of local genes (despite selection) as no longer threatened (since 1850).

Although 17 per cent of reptiles are endemic to the CFR, there are no endemic snake (Serpentes) species out of the 38 species which occur in the CFR (Table 2.1.5). Skinks (Scincidae), girdled lizards (Cordylidae) and chameleons (Chamaeleonidae) comprise two-thirds of the 19 endemic species to the CFR - only one endemic species (Geometric Tortoise *Psammobates geometrica*: Chelonia) is not a saurid. No differences in taxonomic composition are evident between Red Data Book species within and outside the CFR (Table 2.1.5): both regions are dominated by girdled lizards, geckoes (Gekkonidae), typical snakes (Colubridae), and skinks. The Nile Crocodile *Crocodylus niloticus* has never occurred within the CFR.

In contrast to the reptiles, almost half (47%) of the amphibian species in the CFR are endemic (Table 2.1.6). Although all four Heleophrynidae are endemic to the CFR, and only one other species occurs in the rest of southern Africa, there are no significant family differences in species composition or endemism (Table 2.1.6). However, nearly half (44%) of southern African Red Data Book species and all five threatened species are endemic to the CFR. Only the Hyperoliidae do not contain Red Data Book taxa in the CFR.

Over half (52%) of the freshwater fish species in the CFR are endemic (Table 2.1.7). Half the species present and three-quarters of the endemic species in the CFR are barbels (Cyprinidae), which also comprise 83 and 44 per cent of the Red Data Book species in the CFR and the rest of South Africa, respectively. The CFR contributes about two thirds of both the Red Data Book species (71%) and threatened species (58%) in South Africa, despite having only 13 per cent of the subcontinent's fish species (Table 2.1.7).

Table 2.1.5
Status of Red Data Book species and subspecies among families of Reptiles (excluding marine and freshwater Chelonii) in South Africa and the Cape Floristic Region (Branch 1988a). Species totals for southern Africa (south of Angola and Zambezi River) and the CFR and CFR endemics are from Branch (1988b). Headings as in Table 2.1.1.

	All species			Red Data Book taxa										
	RSA	CFR	CFR	Non-CFR					CFR					Shared
Order: Family	Total	Total	End	X	T	R	I	Tot	X	T	R	I	Tot	
Chelonia	11	6	1			1		**1**		1	1		**2**	0
Serpentes Misc	17	4	0		1			**1**					**0**	-
Colubridae	85	25	0			6		**6**		1	2		**3**	2
Elapidae	13	4	0			1		**1**			1		**1**	1
Viperidae	12	5	0		2	2		**4**			1		**1**	1
Amphisbaena	12	0	-			1		**1**					**-**	-
Sauria Scincidae	59	14	5		1	5		**6**			2		**2**	0
Lacertidae	30	10	2			1		**1**			1		**1**	0
Cordylidae	49	14	4	1	2	6		**9**		1	2		**3**	2
Chamaeleonidae	16	5	4			3		**3**		1			**1**	0
Gekkonidae	64	18	3		1	3	1	**5**			2	1	**3**	1
Misc	11	4	0					**0**					**0**	-
Crocodylia	1	0	-		1			**1**					**-**	-
TOTAL	380	109	19	1	8	29	1	**39**	0	4	12	1	**17**	7

Table 2.1.6
Status of Red Data Book species and subspecies among families of Amphibians in South Africa and the Cape Floristic Region (Branch 1988a). Species totals South Africa (incl. Lesotho and Swaziland) and the CFR and CFR endemics are from Passmore and Curruthers (1979) and Branch (1988a). Headings as in Table 2.1.1.

	All species			Red Data Book taxa										
	RSA	CFR	CFR	Non-CFR					CFR					Shared
Family	Total	Total	End	X	T	R	I	Tot	X	T	R	I	Tot	
Pipidae	3	1	1					**0**		1			**1**	0
Heleophrynidae	5	4	4					**0**		2			**2**	0
Bufonidae	12	6	3			1		**1**			1		**1**	0
Microhylidae	13	8	5			1		**1**		1			**1**	0
Ranidae	36	13	4			3	1	**4**		1	1		**2**	0
Hyperoliidae	21	6	1			3		**3**					**0**	-
Misc.[1]	5	0	-					**0**					**-**	-
TOTAL	95	38	18	0	0	8	1	**9**	0	5	2	0	**7**	0

Notes:
[1] Arthroleptidae, Hemisotidae and Rhacophoridae.

Table 2.1.7
Status of Red Data Book species among families of freshwater Fish (Pisces) in South Africa and the Cape Floristic Region (Skelton 1987). Species totals for southern Africa (south of Angola and Zambezi River) and the CFR and CFR endemics are from Jackson (1975) and Scott and Hamman (1984), respectively. Only families with Red Data Book species are listed. Headings as in Table 2.1.1.

	All species			Red Data Book taxa										
	sAf	CFR	CFR	Non-CFR					CFR					Shared
Family	Total	Total	End	X	T	R	I	Tot	X	T	R	I	Tot	
Cyprinidae	76	14	11		3	1		**4**		5	5		**10**	0
Bagridae	5	2	2			1		**1**		1	1		**2**	0
Mochokidae	13	0	-		1			**1**					**-**	-
Anabantidae	4	1	0		1			**1**					**0**	-
Cichlidae	26	1	0			2		**2**					**0**	-
Subtotal	124	18	13											
TOTAL	212	27	14	0	5	4	0	**9**	0	6	6	0	**12**	0

By way of comparison, mammals, birds, amphibians and plants have a similar proportion of species (40%) in the CFR relative to the subcontinent (Table 2.1.8). Butterflies and reptiles have a much smaller proportion (29%) and fish are by far the least well represented (13%) in the CFR relative to the subcontinent. Patterns of endemism within the CFR are quite different among taxonomic groups: plants, fish and amphibians have high ratios (>45%) of endemism, whereas birds, mammals and reptiles have very low ratios (<20%) (Table 2.1.8). There is a very close correspondence between the ratio of endemism to total species richness in the CFR and the ratio of Red Data Book species richness in the CFR relative to that of southern Africa (including the CFR), the exception being those taxa with very low ratios of endemism, which share a high proportion of Red Data Book species between the regions (Table 2.1.8).

The proportion of Red Data Book species relative to total species richness are, except for mammals and birds, much higher within the CFR than in the rest of South Africa (Table 2.1.8): the largest differences are for fish and plants (with CFR values 10.5 and 3.3 times that of southern African values, respectively). The ratio for the remaining taxa varies from 1.5 to 2.0 times that of the rest of South Africa (Table 2.1.8).

Known extinctions in the CFR have been confined to mammals, birds and plants. Although twice as many plants as mammals have gone extinct, the proportion of extinctions to the total number of species in the CFR is 30 times higher for mammals (Table 2.1.8). A small proportion of reptile and butterfly species are threatened by mans' activities: both these groups have a high proportion of naturally rare species. Species with an indeterminate status occur predominantly among nocturnal mammals, plants and butterflies: the status of taxonomic groups with relatively few species is generally better known than that of larger groups (Table 2.1.8). As with Western Australia (Burbidge and McKenzie 1989), the number of extinct birds and reptiles is significantly fewer than that for mammals (X^2 = 16.5 and 8.5, $P < 0.005$, based on expected total species richness, respectively)

Table 2.1.8
Summary statistics for vertebrate classes, butterflies and plants for the Cape Floristic Region (CFR) relative to southern Africa (sAf - including the CFR) and South Africa (RSA - excluding the CFR), extracted from Tables 1-7.
Subscripts are: end = endemic; rdb = Red Data Book species; and, tot = total species.

	Species richness(%)			Red Data Book species (%)			Red Data Book status in CFR (% of CFR_{tot})			
	$\frac{CFR_{tot}}{sAf_{tot}}$	$\frac{CFR_{end}}{CFR_{tot}}$	$\frac{CFR_{rdb}}{CFR_{tot}}$	$\frac{RSA_{rdb}}{RSA_{tot}}$	$\frac{CFR_{rdb}}{(CFR+RSA)_{rdb}}$	Shared between $\frac{CFR+RSA}{CFR}$	Extct	Threat	Rare	Indet.
Mammal.	43.0	7.9	29.1	28.1	42.0	86.5	11.0	5.5	6.3	6.3
Aves	41.5	2.1	7.3	7.1	42.9	100.0	1.4	2.4	1.4	2.1
Reptilia	28.7	17.4	15.6	10.3	34.7	41.2	0.0	3.7	11.0	0.9
Amphibia	40.0	47.4	18.4	9.5	43.8	0.0	0.0	13.2	5.3	0.0
Pisces	12.7	51.9	44.4	4.2	57.1	0.0	0.0	22.2	22.2	0.0
Lepidopt.	29.9	30.8	23.1	12.8	38.0	5.6	0.0	2.6	16.7	3.8
Plantae	42.2	68.2	16.7	4.6	70.6	4.8	0.3	3.3	4.9	8.2

Areas with concentrations of rare species

The richness of Red Data Book butterfly, amphibian, reptile and plant species is highest in the south-west, centred on the Cape Peninsula and adjacent lowlands (Figure 2.1.3). This pattern is mirrored by the distribution of threatened species in the CFR (Figure 2.1.3). Reptiles, amphibians and butterflies also all show a minor concordance of threatened and higher species richness in the mountains of the Uitenhage area.

Butterfly Red Data Book species show several satellite areas with high richness (Figure 2.1.3). These probably reflect collecting intensity and are centred on prominent mountain passes. The south coastal areas of species richness and threatened species reflect the prominence of Thicket species and the development of holiday resorts along the coast.

Amphibian Red Data Book species are largely concentrated on the black-(acid-) water lakes of the southwestern Cape lowlands and the high mountains of the western CFR (Figure 2.1.3).

Reptile Red Data Book species show a strong arid northwest dispersion, with threatened (endangered) species largely concentrated in the Fynbos and Renoster Shrubland lowlands (Figure 2.1.3). A 'vulnerable' species of girdled lizard *Cordylus cataphractus*, threatened by the pet trade, occurs in the mountains of the northwest and extends beyond the region to the north.

Plant Red Data Book species occur throughout the region: only 20 (9%) of the 212 quarter-degree grid squares did not contain a Red Data Book species. Some 90 and 94 Red Data Book plant species occupy the two quarter-degree grid squares on the Cape Peninsula, with high concentrations of threatened species on the Peninsula and adjacent lowlands and in the Elim area. High numbers of rare and indeterminate species occur in the mountain ranges in the southwest, with lesser peaks to the north and east (Figure 2.1.3).

The Olifants River system contains 11 indigenous species of fish, of which eight have Red Data Book status, with five being threatened (Skelton 1987). Seven of the Red Data Book species occur in the southern Cedarberg (Figure 2.1.3). One species, the Chubbyhead Barb *Barbus anoplus*

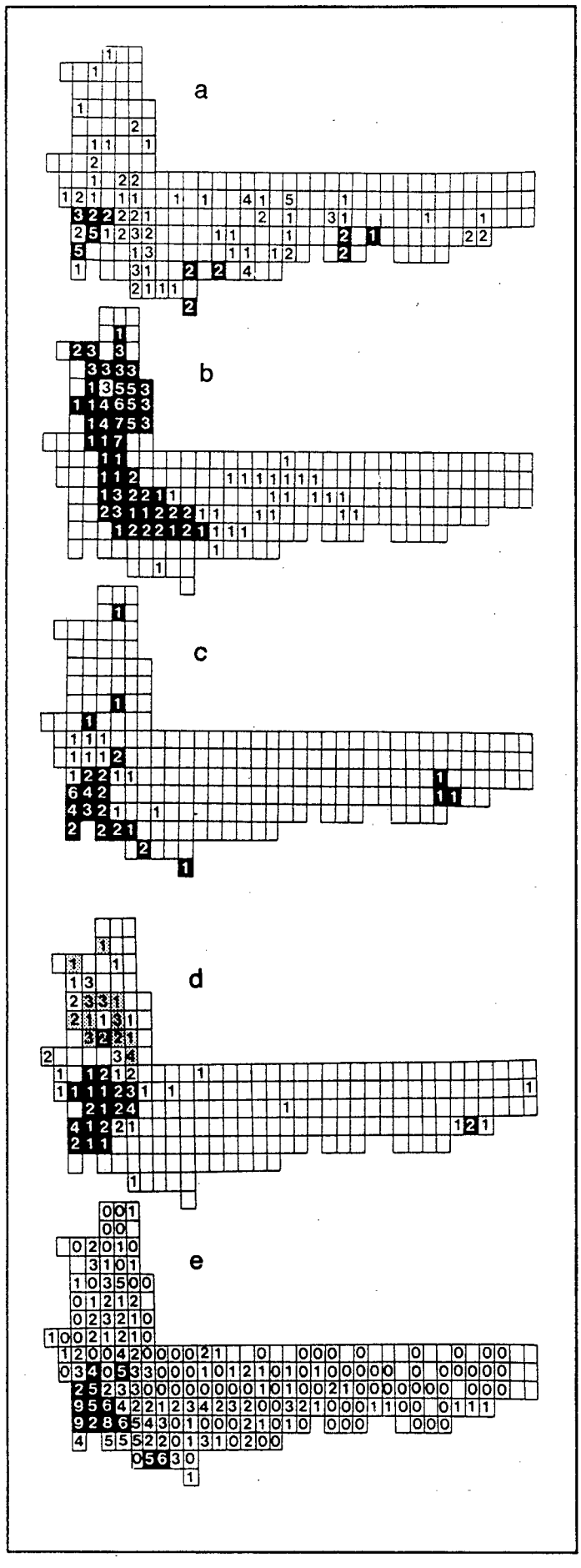

Fig. 2.1.3. Species richness of Red Data Book species in the Cape Floristic Kingdom per quarter-degree grid square. Shaded grid squares (with white numerals) contain threatened species (*i.e.* extinct, endangered, or vulnerable). (a) butterflies, (b) fish, (c) amphibians, (d) reptiles [shading = endangered, light stippling = a vulnerable species threatened by pet trade], (e) plants [0 = 1-9, 1 = 10-19, *etc.*; shading = more than 15 threatened species].

(Cypriniformes: Cyprinidae), is apparently extinct from the system, but is widespread in the east beyond the CFR (Scott and Hamman 1984). Thus the Olifants River contains 83 per cent of threatened and two-thirds of the Red Data Book fish species. The Berg River system shares four of its five species with the Bree River system, which contains an additional three species (Scott and Hamman 1984). Three species in the combined system have Red Data Book status, with two threatened (one shared and one confined to the Berg and two adjacent rivers) and one rare (confined to the Bree and three adjacent rivers). The Gouritz River system contains eight species of fish, two of which are naturally rare: only one species is confined to the Gouritz and adjacent rivers (Scott and Hamman 1984). The Gamtoos River system contains 11 species of fish, none of which are confined to the river or adjacent rivers or have Red Data Book status: one out of the five species common to the combined Gouritz-Gamtoos Rivers is endemic to the combined system (Scott and Hamman 1984). Although not

Table 2.1.9
Distribution of Red Data Book species within major vegetation types in the Cape Floristic Region. Figures in parenthesis are species numbers per km^2. Vegetation types are based on Moll and Bossi (1984), as modified by Hall and Veldhuis (1985) based on Weimarck's (1941) centres of endemism.

	Area (km^2)	No of Red Data Book species						
		Plants	Butterflies	Amphibians	Reptiles	Fish	Birds	Mammals
Thicket:								
West coast	3 555	97 (2.7)	3 (0.1)	0	2 (0.1)	0	4 (0.1)	19 (0.5)
South coast	1 410	122 (8.7)	6 (0.4)	0	1 (0.1)	0	7 (0.5)	19 (1.3)
Renoster Shrubland:								
West coast	7 280	187 (2.6)	6 (0.1)	1 (+)	2 (+)	2 (+)	12 (0.2)	17 (0.2)
Central	3 570	55 (1.5)	2 (0.1)	1 (+)	1 (+)	2 (0.1)	9 (0.3)	21 (0.6)
South coast	6 940	171 (2.5)	1 (+)	0	0	1 (+)	12 (+)	19 (0.3)
Eastern	500	47 (9.4)	0	0	0	0	11 (2.2)	20 (4.0)
Karoo:								
Clanwilliam	583	44 (7.5)	1 (0.1)	0	1 (0.1)	3 (0.5)	7 (1.2)	19 (3.3)
Little	14 530	100 (0.7)	3 (+)	0	0	0	11 (+)	20 (0.1)
Afromontane:								
Forest	1 700	24 (1.4)	1 (0.1)	0	0	0	1 (0.1)	6 (0.4)
Fynbos (Mountain)								
Northern	12 020	365 (3.0)	6 (+)	1 (+)	8 (0.1)	10 (0.1)	1 (+)	7 (0.1)
Peninsula	300	127 (42.3)	5 (1.7)	4 (1.3)	1 (0.3)	0	2 (0.7)	7 (2.3)
Southern	4 660	479 (10.3)	12 (2.6)	4 (0.1)	6 (0.1)	1 (+)	1 (+)	7 (0.1)
Langeberg	1 970	151 (7.7)	3 (0.1)	0	0	2 (0.1)	2 (0.1)	7 (0.4)
Outeniqua	5 690	66 (1.2)	1 (+)	0	0	0	1 (+)	7 (0.1)
Eastern	7 660	31 (0.4)	4 (0.1)	1 (+)	2 (+)	1 (+)	1 (+)	8 (0.1)
Inland	4 980	103 (2.1)	10 (0.2)	0	3 (0.1)	1 (+)	1 (+)	6 (0.1)
(Lowlands):								
South coast	3 110	90 (2.9)	5 (0.2)	0	0	0	1 (+)	9 (0.3)
West coast	3 505	167 (4.8)	3 (0.1)	2 (0.1)	1 (+)	0	1 (+)	10 (0.3)

a Red Data Book species, nor a CFR endemic, the Cape Kurper *Sandelia capensis* (Perciformes: Anabantidae) has become extinct in three rivers in the CFR - the largest reduction in distribution range amongst CFR fish species (Scott and Hamman 1984).

The majority of large mammals and predatory and scavenging birds were probably fairly widespread within the CFR, with the notable exceptions of: the Quagga which may not have occurred historically on the west coast lowlands; the Gemsbok *Oryx gazella* which historically occurred only as far south as Piketberg; the endemic Bluebuck which was apparently confined to the Swellendam area of the South Coast Renoster Shrubland when Europeans first explored the area (prehistorically the species also occurred in West Coast and East Coast Renoster Shrubland); and the endemic Bontebok which occurred throughout South Coast Renoster Shrubland (Skead 1980, Smithers 1983, Rookmaker 1989). However, insufficient data exist for clear patterns to be deduced. All the endemic bird species are Mountain Fynbos species, and consequently have not been notably impacted by humans.

Habitat ranges

Despite the large scale transformation of the lowlands of the CFR, relatively few Red Data Book plant species occur within regions dominated by lowland vegetation types (Thicket, Renoster Shrubland and Lowland Fynbos) (Table 2.1.9). By contrast, Red Data Book mammal and bird species were

predominant in these vegetation types. Furthermore, the majority of large mammal species occurred in these vegetation types, with smaller species in Fynbos vegetation types (mainly Insectivora and Rodentia). Whereas Red Data Book mammal species were fairly widespread between Renoster Shrubland, Thicket and Karoo, Red Data Book bird species appear to have been richer in coastal Renoster Shrubland and Little Karoo than in Thicket, Mountain Renoster Shrubland or Clanwilliam Karoo.

By far the highest numbers of Red Data Book plant, amphibian and butterfly species occur in Southern Mountain Fynbos. The ratio of species to area is far higher for the Mountain Fynbos on the Cape Peninsula for plants, amphibians and reptiles. Butterflies and plants are also well represented (on an areal basis) in South Coast Thicket.

Although these data are crude they suggest that similar overall patterns occur in species habitat preferences among plants, butterflies and amphibians, with a preponderance of rare and threatened species in the southwest in Fynbos vegetation. By contrast, reptile species were richest in the more arid Fynbos vegetation in the northwest.

Types of rarity

The majority of Red Data Book plant amphibian, reptile and butterfly species in the CFR are localized endemics (Table 2.1.10). Mammals and fish tend to have a low proportion (<30%) of localized species: there are no localized bird species in the CFR. Species with low densities per unit area and wide distribution ranges dominate rarity types in birds, comprising predominantly predatory and wetland species, and the Orchidaceae in plants (Table 2.1.10). The largest proportion of mammals and fish historically occurred over large areas (even though most fish species were limited to a single river system) and were relatively common within their distribution range (Table 2.1.10). A fair proportion of Red Data Book plant and reptile species were also formerly common over wide distribution ranges.

Table 2.1.10
Types of rarity (scarce and restricted) or non-rarity (common) exhibited in the historical distribution ranges of Red Data Book species in the Cape Floristic Region. Analysis is confined to categories X, E, V and R. Only those plant families with more than 35 species in these categories are included.

Taxon	Total spp with data	Localized (%)	Scarce (%)	Common[1] (%)
PLANTS				
Ericaceae	(79)	82	18	0
Asteraceae	(53)	72	28	0
Proteaceae	(123)	75	18	7
Rutaceae	(74)	74	19	7
Iridaceae	(141)	67	28	5
Restionaceae	(41)	60	33	7
Orchidaceae	(39)	28	67	5
ANIMALS				
Amphibia	(7)	86	14	0
Reptilia	(16)	69	25	6
Lepidoptera	(45)	64	36	0
Mammalia	(29)	29	24	48
Pisces	(12)	17	25	58
Aves	(21)	0	86	14

Notes:
[1] Includes peripheral species historically common elsewhere.

Threats

The most important threats to Red Data Book taxa in the CFR are agriculture and alien invasive plants (Table 2.1.11). However, each taxon is influenced by different factors. Thus, Red Data Book bird and mammal species are most threatened by hunting and poisoning, plant and fish species by alien introductions, amphibian and reptile species by agriculture and butterfly species by urbanization (especially the development of coastal holiday resorts). Factors affecting most taxa include: agriculture, alien invasive plants, aseasonal and too frequent fires, dams and roads, and afforestation.

Table 2.1.11
Threats to taxa in the Cape Floristic Region, in terms of numbers of species affected. Numbers of species have been scaled so that the threat category with the most species equals 10.

Threat	Score								Rank
	Plant		Butterfly	Fish	Amphibian	Reptile	Bird	Mammal	of
	Elim[1]	Total[2]							threat
# spp in largest category	49	84	9	10	4	5	8	20	
Agriculture	4.4	5.3	8.9	9.0	10.0	10.0	1.3	1.5	46.0
Alien invasive plants	10.0	10.0	4.4	6.0	0	4.0	0	0	24.4
Hunting/poisoning	-	-	0	0	0	0	10.0	10.0	20.0
Fire (frequency & timing)	2.3	3.7	5.6	0	2.5	2.0	2.5	0	16.3
Urbanization/industrialization	5.6	3.8	10.0	1.0	0	0	0	0	14.8
Commercial collecting[3]	1.6	1.3	0	0	0	10.0	0	0	11.3
Dams/wiers/roads	1.7	0.9	2.2	4.0	2.5	0	1.3	0	10.9
Alien predators	-	-	0	10.0	0	0	0	0	10.0
Pollution[4]	0.2	0.4	0	4.0	5.0	0	0	0	9.4
Afforestation	1.0	0.9	2.2	0	2.5	2.0	1.3	0	8.9
Mining/quarrying	0.8	1.2	0	1.0	0	4.0	0	0.5	6.7
Grazing/browsing	0.8	2.9	0	0	0	0	3.8	0	6.7
Hybridization[5]	0	0	0	0	2.5	0	0	0.5	3.0
Intolerance of human presence	-	-	-	-	-	-	2.5	0	2.5
Casual flower picking	1.5	0.2	-	-	-	-	-	-	0.2
Presumed genetic decline[6]	4.5	1.1	0	0	0	0	0	0	1.1
Mowing/trampling	0.8	1.0	-	-	-	-	-	-	1.0

Notes:
[1] Data for the plant species of the Agulhas region (Hall and Veldhuis 1985). Typical of Fynbos little agricultural transformation has occurred, consequently this threat is under-represented relative to the entire Cape Floristic Region. Values in this column do not contribute to the Rank of threat.
[2] Data for 232 species for which threats are listed in Hall and Veldhuis (1985).
[3] Collecting was dismissed as a possible threat to butterflies by Henning and Henning (1989).
[4] Including: Fertilizers, pesticides, salinization, eutrophication, and acid rain.
[5] Hybridization was apparently not considered for plants.
[6] Caused by inbreeding depression and stochastic processes inherent to small populations - categorization invariably speculative: no genetic studies of plants have been undertaken.

Only fish species are influenced by alien predators (mainly other fish species). Although the alien Argentinian Ant *Iridomyrmex humilis* may disrupt plant seed dispersal by excluding species of indigenous ant (Bond and Slingsby 1983), no plant species appears to have been impacted sufficiently to record this as a threat. The impact of *I. humilis* on butterfly larvae - ant associations has never been ascertained: this threat may be important for species with limited distribution ranges in peri-urban areas, where alien ant populations may be large (Brooke *et al.* 1986).

Only bird species are intolerant of continued human presence, reflecting the vulnerability of large animals which nest in accessible habitats (e.g. wetlands). Only reptiles are seriously impacted by commercial collecting, although the effect of commercial plant exploitation is insidious as seed banks are notoriously difficult to estimate. Collecting of butterflies as a source of species reduction was dismissed by Henning and Henning (1989) in their introduction, based on results obtained from extermination trials in America (Pyle *et al.* 1984), and consequently was not included as a threat to any species. Nevertheless, Claassens and Dickson (1980) state that "... the particularly contemptible instance of the destruction of a very rare and beautiful butterfly through gross over-collecting ..." was responsible for the Department of Nature and

Environmental Conservation of the Cape promulgating a 'protected list' of butterflies in 1976. They also note that *Oxychaeta dicksoni* probably went extinct at several localities due to commercial over-collecting. Commercial collecting may still be a problem, despite the legislation (Greig 1981). Although the Red Data Book account (Henning and Henning 1989) lists this vulnerable species' low densities and small population sizes as factors contributing to its rarity, there is no mention of possible over-collecting. Clearly, the conservation significance of amateur and commercial collecting of rare butterflies urgently requires a balanced reappraisal.

DISCUSSION

History and location of threats

Human impact on species richness in the CFR appears to largely reflect the relative carrying capacity of soils and the distribution of animal and plant species in these habitats. Thus, nutrient-rich soils supporting Renoster Shrubland and Thicket vegetation were the first to be impacted by man and have been impacted the most extensively.

Renoster Shrubland

Initial exploitation of Renoster Shrubland by European settlers was primarily by way of shooting large mammals for provisions (Skead 1980). Large mammals provided the early stockfarmers with meat and clothes (Boucher 1986). Although a permanent European settlement only commenced in 1652, by 1657 the first proclamation limiting the hunting of wildlife was issued. By the late 1680s large mammals had virtually disappeared within 200 km of Cape Town (Gunn and Codd 1981), and by 1800 large mammals were scarce in the CFR (Pringle 1982). The grasslands of the Renoster Shrubland were initially used for grazing, although hay was reaped for use in Cape Town (Skead 1980). Expansion of the early colony was primarily due to the increase in cattle herds and the exhaustion of pastures (Boucher 1986). By the 1750s the first reports of shrub encroachment were recorded for West Coast Renoster Shrubland, and similarly for South Coast Renoster Shrubland in 1775 (Skead 1980). By 1800 the transformation from grassland to shrubland was complete (Muir 1929, Cowling *et al.* 1986), and hay was no longer available (Skead 1980).

We can therefore conclude that the extermination of large mammals from the lowlands of the CFR was caused by hunting rather than by competition for grazing. Recorded introductions of epizootic diseases (e.g. rinderpest in the 1890s) and game-proof fencing (this century) played little role in the CFR, in contrast to much of the rest of Africa (Macdonald 1989). Furthermore, the extinction of the large mammals occurred more or less concurrently with the transformation of Renoster Shrubland from a grassland to a shrubland. Although the extinctions probably preceded the transformations, very few grazing species probably would have been able to survive in the transformed vegetation. The Reedbuck and Oribi *Ourebia ourebi* are candidate mammal species small enough to have perhaps survived hunting, but which may have been impacted by the transformation from shrubland to grassland.

Moister areas of Renoster Shrubland have been converted to vineyards and much of the remainder to winter wheat and pasture (Boucher 1981, Cowling *et al.* 1986), mainly after the First World War (Macdonald 1989). Currently, some 71% of Renoster Shrubland has been transformed, although 85 per cent both of West and South Coast Renoster Shrubland are transformed (Rebelo in press). Remaining patches are on steep slopes and hill tops, which, although currently unsuitable for farming, are being converted to cropland with the aid of technological advances. Land subsidies also favour conversion to cropland, despite legislation prohibiting the destruction of virgin lands (McDowell 1986). Consequently,

Renoster Shrubland is now largely unsuitable for restocking with large mammals, and land is too expensive to acquire for reserves. It is important to note that the extermination of such a large number of African mammalian species, generally regarded as resilient to hunting owing to a long association with mankind (Owen-Smith 1989), probably reflects the long history (350 years) of European exploitation in the CFR, more specifically the long period prior to the establishment of wildlife protection movements (Pringle 1982). The high cost of land and the absence of large mammals together account for the small proportion of Renoster Shrubland currently preserved - 0.5 per cent of the original area of the vegetation type (Rebelo in press).

Although we can estimate loss of large mammal species from Renoster Shrubland, it is difficult to determine what plant losses have been incurred, since the transformation took place prior to the advent of scientific observations in the region (Macdonald 1989). It appears that Renoster Shrubland, even during its grassveld stage, consisted of widespread plant species (Cowling *et al.* 1986), with rare species being scarce rather than localized and endemic species being widespread throughout the vegetation type. Many of the shrub species which now dominate Renoster Shrubland are pioneers (tolerant of short fire cycles) in Fynbos on granitic substrata, and the geophytes and annuals are shared with Thicket vegetation (Boucher 1981). However, it is unclear whether any localized species went extinct. Any extinctions must have occurred during the transformation from grassland to shrubland at around 1750, before the extensive botanical exploration of the CFR, which commenced in earnest during the 1770s (Gunn and Codd 1981) - certainly few species have become extinct with the conversion of Renoster Shrubland to commercial crops during the past century. Nevertheless, if Renoster Shrubland contained many endemics or localized species, then it is curious that there are no species recorded by collectors between 1600 and 1750 that have never been recorded since. Similarly, there is not a single species of extinct amphibian, reptile or fish in Renoster Shrubland. It appears more probable, therefore, that Renoster Shrubland contained very few localized endemic animal or plant species. However, little is known about the invertebrates, other than that the CFR is a region of high diversity in flies (Bowden 1978), beetles (Scholtz and Holm 1985) and bees (Michener 1979).

Fynbos of the Mountains

The situation in Fynbos vegetation in the mountains contrasts dramatically with Renoster Shrubland. Firstly, almost half of Mountain Fynbos is protected, primarily in State Forests and Mountain Catchment Areas (Grove 1987, Rebelo in press). This is primarily due to South Africa's acute water shortage and the need to protect mountainous catchment areas, rather than any attempt to protect the flora itself, although some areas (with spectacular scenery) have subsequently been assigned a conservation status based on elements of their flora (Rebelo in press). Furthermore, the discovery that alien invasive plant species may reduce streamflow by 50% (Versveld and Van Wilgen 1986) and the potential for uncontrollable fires, resulted in the implementation of an efficient alien removal campaign in Mountain Fynbos (Macdonald 1989). The coincidence of low agricultural potential, regional lack of water, and invasion by alien species which are relatively easy to control, with the large number of locally endemic plant, butterfly, reptile and amphibian species has prevented a catastrophic extinction of species in the CFR. Similarly, the six CFR endemic bird species are well protected, and under no threat at present.

Local endemism in Fynbos (both in the mountains and lowlands) is high for plants, butterflies, and amphibians. This may stem from these taxa comprising relatively 'sessile' groups. Thus many localized amphibian species are confined to acid or black-water wetlands on mountain slopes or in the lowlands. The low

nutrient status in Fynbos soils has resulted in convergence between plant's seed dispersal and larval development in butterflies. Since many Fynbos plant species load their seeds with nutrients, an efficient anti-seed-predation system is essential (Bond and Breytenbach 1985). One such mechanism is to utilize ants to bury seeds (myrmecochory) where rodents and birds cannot consume them. However, this is at the expense of efficient dispersal, with dispersal distances typically in the order of a few metres (Bond and Slingsby 1983). Similarly, the low nutrient status of foliage (specifically the high carbon to nitrogen ratio) prevents grazing or browsing by, amongst other animals, butterflies (Cottrell 1985). The over-represented Lycaenidae utilize ants as a protein-rich food source in later larval stages (Cottrell 1985). Thus, butterfly species may be restricted to areas where the correct ant species and both adult and larval feeding plant species co-occur.

The pattern of Red Data Book plant distribution is strongly correlated with that of total plant species richness, with the Southern and Northern Fynbos centres of endemism by far the richest in species (Rebelo and Tansley submitted). Whether the distribution of Red Data Book species in other taxa also reflects the pattern of species richness within Fynbos vegetation is not known, as distribution data on a suitably fine scale are not readily available.

Fynbos of the lowlands

The conservation status of Fynbos in the lowlands is quite different to that of the mountains. Of the original extent half has been transformed to agriculture and only three per cent is preserved in nature reserves (Rebelo in press). Based on the Proteaceae, two centres of plant endemism can be recognized in both South coast and West Coast Lowland Fynbos (Rebelo and Siegfried 1990). One of these centres coincides roughly with the Greater Cape Town Metropolitan area. Based on the distribution of Red Data Book Proteaceae species, the Greater Cape Town Metropolitan area contains significantly more Red Data Book species than predicted by species richness, even though the Proteaceae are under-representative of species richness in these grid squares (Rebelo and Tansley in press). A total of 74 Red Data Book plant species occur within Lowland Fynbos in the Greater Cape Town Metropolitan area on 485 *ha* of remaining untransformed land (McDowell *et al.* in press). In addition, two endangered amphibian species occur in acid-water lakes (confined to Fynbos vegetation) within the metropolitan area. Only eight Red Data Book plant species occur within the more extensive Thicket vegetation in the area. The location of Cape Town is unfortunate: had it been situated any distance more than 70 km to the north, the number of Red Data Book plant species threatened by urbanization would probably be an order of magnitude lower.

Fortunately, the Fynbos centre of endemism extends 60 km northwards beyond the metropolitan area. This area to the north of the present zone of urbanization has been identified as the top priority site within the CFR for conservation action (Jarman 1986). However, this area is designated for future urban expansion (McDowell *et al.* in press). As with the other lowland centres of endemism, the non-urban portions of the Greater Cape Town Metropolitan area are extensively transformed by alien invasive plant species (Boucher 1981, Macdonald and Richardson 1986), placing an additional cost (that of clearing aliens), over and above that created by speculators awaiting urban development, on land to be acquired for reserves.

This pattern of high numbers of local Fynbos endemics within the Greater Cape Town Metropolitan area does not occur in reptiles or butterflies. Reptiles predominate in the Thicket sands. There is a preponderance of localized endemic butterfly species on the Tygerberg and Darling ranges of hills and in Thicket vegetation. This pattern of distribution of butterflies should be investigated to determine whether the species are ecotonal, perhaps having larval and adult foods in

different vegetation types. Thicket vegetation, being close to the sea, is under heavy pressure for the development of coastal resorts (Cowling and Pierce 1985).

In contrast to the distribution patterns of all other taxa, that of fish species does not reflect a particular threat operative in a localized area. Rather it reflects the historical origin of the endemic species, having resulted from past connections of the Olifants River System to the Orange River in the north (Skelton 1986). Thus threats to fish do not include afforestation and fires, which would probably have played a role had localized fish species been more evenly distributed within rivers in Fynbos. The majority of the species are now confined to the upper river valleys, mainly within Fynbos vegetation, where introduced alien predatory fishes have been unable to colonize and where there is minimal agricultural degradation of the catchment (Gaigher *et al.* 1980, Skelton 1987).

Forest

The paucity of Red Data Book plant (and animal) species in Afrotropical Forest may simply reflect the decrease in species richness of these subtropical vegetation types with increasing latitude and the lack of endemic species. Alpha species richness in Forest in the west of the CFR is one third that of Natal for plants and birds and 44 per cent for mammals (Geldenhuys and Macdevette 1989). Despite extensive exploitation of these forests for wood which has eliminated many stands (Skead 1980), very few forest species have Red Data Book status. The Redeyed Dove *Streptopelia semitorquata australis* decreased locally in abundance following logging of the forests, but, after the introduction of the Beira subspecies *S. s. semitorquata* into the western Cape during the 1930s, the resulting hybrid swarm has expanded into woodlots and urban areas (Brooke *et al.* 1986)

Threats, extinctions and size in mammals

In the CFR, extinction in mammals is related to body size. Virtually all species larger than 300 kg were hunted to extinction and all except one mammal species larger than 100 kg are threatened. Conservation action has been geared towards re-introducing large mammals (including species not recorded historically, but excluding large predators) in the CFR (Table 2.1.3). The smallest extinct species is 14 kg, and the smallest threatened species, with the exception of one 90 g rodent, is 5 kg. These patterns contrast strongly with those from mainland Australia (Burbidge and McKenzie 1989), where larger mammals were not much impacted by hunting and poisoning and where extinct and threatened species range from 35 g to 5.5 kg in size. Man-induced aridification, and the introduction of alien predators and large alien herbivores, which have had the greatest impact on mammals in Australia, appear not to have operated in the CFR. The proportion of species which have gone extinct, declined, or neither, is nearly identical ($X^2 = 0.26$ $P > 0.05$) between the CFR and Australia.

However, the patterns related to soil nutrient status and aridity appear similar between the CFR and Australia (areas listed in inverted commas below). Thus arid vegetation (Karoo and "Deserts and Pastoral", with little land transformed to agriculture but extensively grazed) and nutrient-rich soils (Renoster Shrubland, Thicket and "Wheatbelt"), which have been most extensively transformed to agriculture, have the most extinct and threatened species. Similarly, the "Darling" region in Australia is analogous to Fynbos and Forest, and parallels it in having far fewer mammal species that are extinct or threatened (Burbidge and McKenzie 1989).

The CFR differs from Australia in that its natural vegetation is relatively resistant to the introduction of alien mammals (Breytenbach 1986). Thus the three rodents are largely commensal with man, and introduced Fallow

Deer *Cervus dama* and Himalayan Tahrs *Hemitragus jemlahicus* are extremely localized in occurrence. The success of the Tahr can perhaps be explained by the extinction of leopards on Table Mountain. This can again perhaps be explained by the low fertility of Fynbos which is unsuitable for large mammals, and competition with sheep, goats and cattle in Renoster Shrubland and Thicket vegetation which would have prevented its establishment. By contrast, Fynbos is highly susceptible to invasion by certain guilds of plants (large woody shrubs or trees with either canopy-stored seeds only released after fire) (Richardson *et al.* 1990), and Renoster Shrubland and Lowland Fynbos appear susceptible to invasion by annual grasses which replace the geophytes (Vlok 1989).

The results for the CFR suggest that despite the possibility of a Pleistocene overkill and the marked fluctuation of large mammal populations between the Pleistocene glacials and interglacials (Klein 1983), and the probable decline of the Bluebuck due to competition with sheep and cattle kept by Khoisan tribesmen (Smithers 1983), large mammals were further heavily impacted by the arrival of Europeans in the region. That this pattern of elimination has not occurred throughout Africa is thus probably not due to any inherent adaptations of large mammals to survive with *Homo sapiens*, but a reflection of the short period between European colonization and the development of conservation awareness in the rest of Africa. Thus southern Africa, where European colonization is older than in the rest of sub-Saharan Africa, has been impacted the most. Consequently, it is fallacious to presume that large African mammals are adapted to man's hunting techniques: as early as the 18th century, technology was adequate to eliminate most mammals larger than 50 kg.

Conservation strategies: problems with target (flagship) species

The juxtaposition of Renoster Shrubland and Fynbos, with their dichotomy in soil fertility, plant and animal species composition, land values and conservation status, has resulted in some unfortunate misconceptions amongst conservation agencies. As a consequence of lower land costs, Fynbos has been favoured for reserve acquisition for restocking the large mammals extinct in the CFR. As a consequence of the extremely poor grazing (Tainton *et al.* 1989), these reserves have been bushcut, ploughed, replanted with pastures of alien invasive grasses, fertilized, enriched with copper and other deficient minerals (both in element form and as salt licks), and burned as frequently as is possible (Millar 1970, Greyling and Huntley 1984, Zumpt and Heine 1977, Novelli 1986, Scott 1986). These 'veld improvement' (Scott 1986) exercises have invariable proved futile, with large mammal species not establishing primarily due to mineral deficiency diseases and concomitant high parasite loads (Barnard and van der Walt 1961, van Rensburg 1975, De Graaf *et al.* 1976, van der Walt *et al.* 1976a, b). This can be construed as supporting evidence that large mammals were not a permanent component of Fynbos vegetation. The impact of these practices on plant species richness was seldom considered. As one example, the Bontebok National Park was relocated during 1961 from a Limestone Fynbos site, where deficiency diseases were limiting population growth, to a site with Fynbos on Enon conglomerates. The latter site was incorrectly stated to support Renoster Shrubland (Jarman 1986), even though a survey (Grobler and Marais 1967) showed some 64 per cent of the reserve to comprise Fynbos. This reflects a tendency to overemphasize relatively unconserved vegetation types, especially in ecotonal areas, possibly as a result of motivation requirements for acquiring reserves being linked to the conservation status of vegetation types.

There is no doubt that linking conservation to the preservation of attractive and charismatic species engenders public interest and participation (Ferrar 1989). Provided that the limitations of this approach are appreciated by reserve managers, it offers rapid gains. Far too often, however, preservation of target large mammals has gone hand in hand with "habitat improvement", to the benefit of the target species and the detriment of other species and ecological processes (Rice 1990, Rebelo in press).

By contrast with Fynbos, the acquisition of provincial nature reserves in Renoster Shrubland has largely centred on the preservation of the Geometric Tortoise (Rebelo 1990). Thus out of six provincial nature reserves containing Renoster Shrubland (Jarman 1986), four were established solely for protecting this tortoise. This is possibly a combination of the Geometric Tortoise being the largest endangered species extant in Renoster Shrubland, and the exceedingly high expenses that would be incurred by any attempt to reintroduce viable populations of large mammals into a Renoster Shrubland reserve. In contrast to large mammals, the life cycle of the Geometric Tortoise is such that its efficient preservation also guarantees the preservation of coexisting plant species (Greig 1984). Coupled with its considerable public appeal, it is thus an ideal 'flagship' or 'target' species (Ferrar 1989).

The use of even such apparently suitable "flagship" species has its drawbacks, however. Two of the reserves have recently been deproclaimed, as viable tortoise populations have not persisted within them. The associated vegetation or its species composition was not considered in the decision to deproclaim, and consequently the only existing viable population of *Leucadendron flexuosum* (Proteaceae; Hall and Veldhuis 1985) has been exterminated (Wood 1991).

The inability of Fynbos to support high densities of herbivores and grazers may explain the paucity of species of plants, amphibians, reptiles and birds threatened by alien introduced mammal species (chiefly predators), as appears to have occurred in other areas throughout the world (Atkinson 1989). With the exception of fish, only the Himalayan Tahr, the Argentine Ant, and the domestic cat *Felis catus* appear to have had a noticeable impact on indigenous vegetation or animals (Macdonald and Richardson 1986). The majority of other alien animal species have had their impacts confined to man-modified areas, usually within urban and cultivated areas (Brooke *et al.* 1986). With the exception of *F. catus* hybridizing with *F. lybica* (Smithers 1983, but see Brooke *et al.* 1986, who maintain that the threat is exaggerated), naturalized alien animals (excluding commensals, such as cattle and feral dogs) do not feature as a threat to any Red Data Book species of terrestrial animal or plant in the CFR (Breytenbach 1986).

CONCLUSIONS

The Cape Floristic Region must rank globally as one of the foremost conservation priorities. The high endemicity of plant, butterfly, fish and amphibian species makes the region distinct from that of the rest of the subcontinent. Fortunately, by far the majority of endemic species within the most speciose plant and animal families in the CFR occur in Fynbos, which is the best conserved vegetation type owing to the low agricultural potential of Fynbos soils and the need to conserve water in a predominantly arid region. Large scale extinction would probably have occurred had there been a concentration of species in the agriculturally important Renoster Shrubland and Thicket vegetation: those few endemic mammals, birds and reptiles confined to these vegetation types are either extinct, threatened or have been rescued at the brink of extinction. Available evidence does not indicate that many Renoster Shrubland plant species have gone extinct in historical times, but rather that Renoster Shrubland was dominated by grasses prior to a transformation to shrubland caused

by overgrazing during the 18th century. Nevertheless, large mammals have formed the focus of conservation efforts in the CFR, to the detriment of Fynbos plant and animal species. Fortunately, increasing emphasis is being placed locally on the plant species.

Consequently, even though Renoster Shrubland is the most heavily transformed of the vegetation types within the CFR, its preservation is not as urgent as that of Lowland Fynbos in terms of threatened species. Although agriculture and alien plant invasion currently rank as the most important overall threats to species in the CFR, and hunting and poisoning as the historically reason for the extinction of many large mammals, it is urbanization that is the greatest threat to floral diversity at present. Thus although 85 per cent (7 300 km^2) of the original extent of West Coast Renoster Shrubland has been converted to agriculture, the impact of the 765 km^2 transformed by urbanization has been equivalent in terms of species threatened. This is not due to the more drastic transformation of urbanization, as extremely few Fynbos and Renoster Shrubland plant species are able to tolerate agricultural perturbations such as plowing. Rather it is the location of the largest urban area within a lowland Fynbos centre of endemism that is responsible for the high ranking of urbanization as a threat in the CFR. Thus it is the area within and adjacent to the Greater Cape Town Metropolitan region which contains the highest concentration of threatened plants and animals. Urgent, expensive and novel action is required to prevent one of the centres of endemism within the CFR from being eliminated.

At this stage in the conservation of the CFR we have little knowledge of functionally-important, indicator, or keystone species. Pattern of movement of pollinators, seed dispersers, herbivore/grazers and predators among vegetation types and specifically seasonal movements between Lowland and Mountain Fynbos are not understood. Research must be urgently targeted at identifying keystone taxa which will serve the function of both indicator and flagship (target) species. The status of conserved areas within the CFR should be upgraded to reflect the region's international importance in conserving biotic diversity. A minimum requirement is that the entire CFR should be declared a Biosphere Reserve, as proposed by Burger's *et al.* (1990), and should be the target of international conservation action, on par with that being given to the tropical rain forests.

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Part 2. Causes of Rarity

2.2.1

Is Red Data Book status scientifically credible?

Rabinowitz categories of rarity and the Proteaceae of the Cape Floristic Region

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Is Red Data Book Status scientifically credible?

Rabinowitz categories of rarity

and the Proteaceae of the Cape Floristic Region

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ABSTRACT

Rarity has seldom been rigorously defined. Yet Red Data Books are a cornerstone of nature conservation efforts. Rabinowitz proposed a typology using geographical extent, habitat specificity and local population size, giving seven categories of rarity. I compared the two approaches using distributional data from the Proteaceae in the Cape Floristic Region. Three forms of Rabinowitz rarity accounted for 79% of species. Localized species with dense populations and restricted habitats were under-represented in Red Data Books, and changed status most frequently between editions. Total population size of a species appears to be a crucial component missing in the Rabinowitz typology. Red Data Book status appears to be labile, depending on whether emphasis is placed on geographical extent or population size. Taxonomic biases among genera where predictable from their ecological requirements. The three components of Rabinowitz rarity were correlated, possibly due to habitat generalists being better able to colonize isolated vegetation patches. The absence of this correlation and the paucity of localized habitat specialists in the United Kingdom suggests a historical scenario. The possible implications of this scenario on global conservation strategies is outlined.

INTRODUCTION

Rarity is of considerable applied and theoretical importance in nature conservation, and rare species justifiably form the focus of conservation efforts (Bratton & White 1981; Kruckeberg & Rabinowitz 1985; Rabinowitz *et al.* 1986). An understanding of the causes and consequences of rarity will determine strategies for preserving rare taxa (Rabinowitz 1981). The most comprehensive regional accounts of rarity are the Red Data Books, which are widely used to determine conservation priorities and to engender public support and finance for specific projects (Synge 1981; Ferrar 1989).

Rarity, however, has seldom been rigorously defined, possibly because of its diverse origins (Kruckenberg & Rabinowitz 1985; Fiedler 1986). The concept of rarity varies among researchers and the boundaries between rare and common taxa are subjectively determined (Harper 1981).

A lack of pertinent distributional data further confounds categorization of rare taxa. Furthermore, taxonomic treatises differ considerably in their species delimitations, especially those of rare species (Kruckeberg & Rabinowitz 1985).

A typology using geographical extent, habitat specificity and local population size, each long recognized as important components of rarity (Drury 1974), has been used to describe "seven forms" of rarity (Rabinowitz 1981; Kruckenberg & Rabinowitz 1985). Cody (1986) used these components of rarity to designate gamma-, beta- and alpha- rares, based on the component of species diversity in which the species is restricted.

The Cape Floristic Region (CFR: Fig. 2.2.1.1) is the smallest of the six floristic Kingdoms (Takhtajan 1986). It is characterized by a very high plant species richness (8600) (Bond & Goldblatt 1984); an endemicity higher than most tropical and temperate regions (68% of species, 20% of genera, 5% of families) (Bond & Goldblatt 1984; Gentry 1986; Cowling & Holmes in press); and, a very high proportion of Red Data Book taxa (15%: Hall & Veldhuis 1985). However, rarity in the CFR has never been defined, despite almost two-thirds of the categorized (i.e. X, E, V, and R) species in the Red Data Book being listed as "Rare".

In fact, no attempt has ever been made to relate the subjective assessments of Red Data Book rarity with the typology proposed by Rabinowitz. More importantly, the features biasing an assessment of Red Data Book rarity and the relative roles played by the identified components of Rabinowitz rarity have seldom been addressed in the literature.

In this paper I address how the Red Data Book status for the Proteaceae of the CFR compare with Rabinowitz' typology of rarity. Specifically, is rarity a definable trait or merely a nebulous concept which defies definition?

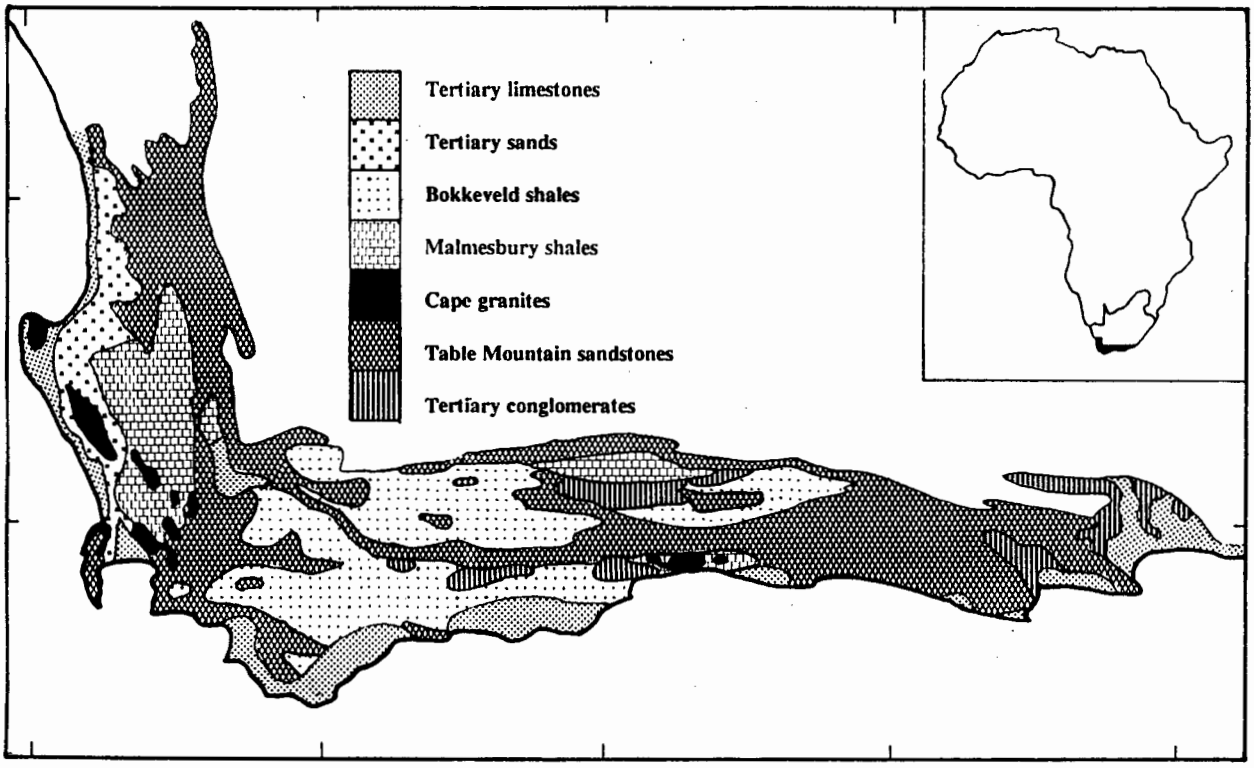

Fig. 2.2.1. 1. Location of the Cape Floristic Region showing the extent of the major geological formations.

Distribution range / Habitat requirements	Widespread (W)		Localized (L)	
	Broad (B)	Restricted (R)	Broad (B)	Restricted (R)
Population density: Somewhere dense (D)	WBD	WRD	LBD	LRD
Everywhere sparse (S)	WBS	WRS	LBS	LRS

Fig. 2.2.1.2. Rabinowitz categories of rarity and codes used in the text.

STUDY PLANTS

I selected the Proteaceae as probably the best known family in the CFR, taxonomically and ecologically, with distributional data available at a finer scale than for other families (Rebelo & Siegfried 1990). Specifically, the Proteaceae have been the focus of a detailed Red Data Book evaluation in 1985 by a panel of conservation officials, taxonomists and ecologists (Tansley 1988), so that there are no Uncertain (U) or Indeterminate (I) species. Furthermore, the distribution patterns of Proteaceae mirror the distribution patterns of other characteristic CFR plant families and major genera for which data are available at a quarter-degree (24 X 26 km) grid system (Rebelo & Siegfried 1990). The Proteaceae contains 14 genera and 333 species and distinct subspecies (hereafter referred to as species) in the CFR, which form a characteristic and often dominant feature, in terms of cover and stature, of Fynbos vegetation. The species range from small understorey shrubs to 3 m-tall overstorey shrubs. Only three of the 331 Proteaceae species and subspecies considered herein are not endemic to the CFR. Thus considerations of rarity within the CFR will not be altered by studies of larger geographical regions. The two additional species (and genera) excluded from the analysis are: *Brabejum stellatifolium*, the only member of the Grevillioideae, and *Faurea macnaughtonii*, confined to a single forest patch near Knysna.

METHODS

I classified Proteaceae species according to Rabinowitz rarity status (Fig. 2.2.1.2) using published and unpublished data on species distribution, habitat specificity and population sizes as follows.

Species distributions of Proteaceae have been recorded on an eighth-degree grid scale (12X13km^2) (Rebelo & Siegfried 1990), and comprise all historical (herbarium) records which could be assigned to grid squares. Anthropogenic range reduction was ignored. I used three measures of geographical range:

(i) area occupied - the number of eighth-degree squares occupied;

(ii) minimum connected area occupied - the minimum number of orthogonal grid squares required to link and include all recorded occurrences; and,

(iii) total geographical area occupied - the product of the number of grid squares comprising the north-south and east-west limits of the overall distribution range.

Of these, the latter appears to most closely approximate Rabinowitz's (1981; *et al.* 1986) concept of geographical distribution range. Since the Proteaceae data are continuous, I determined the cutpoint between widespread and localized as the number of grid squares at the intersection between the cumulative proportional decrease in critically rare (R) and cumulative proportional increase in non-Red Data Book (i.e. not R,V,E,X) species. Threatened rare species (V,E,X) were ignored for this determination, since many species are categorized as threatened because of a reduction in distribution range, or because of anthropogenic threats which do not affect natural rarity.

Although Rabinowitz (1981) categorized population sizes into somewhere large and everywhere small, her descriptions suggest that the codes do not refer to population size (as has

been used by, for example, Ferrar (1989)), but to population density. I have thus renamed her categories "somewhere dense" and "everywhere sparse", roughly equivalent to Schoener's (1987) "diffusive" and "suffusive" rarity, respectively, and more in line with Cody's (1986) "alpha rarity". I feel that this typology, in conjunction with habitat specificity and geographical distribution, is more likely to reflect the species' total population size, than local population numbers *per se*. Species were recorded as occurring only as scattered individuals (= everywhere sparse), mainly as scattered individuals, mainly in dense stands or exclusively as dense stands. The terms scattered and dense were subjectively based on the visual impact of the species in the plant communities in which they occur. I attempted to quantify these subjective categorizations by assigning a modal distance between plants (to the nearest metre) within a typical population based on field experience (Rebelo & Rourke, unpublished data). These "ballpark" figures are probably no more subjective or inaccurate than classifying species as sparse or dense as described in Rabinowitz *et al.* (1986).

It proved difficult to assign species to habitat specificity categories. Types of habitats can perhaps be subjectively categorized, but little data exist for the diverse habitats occupied by the more widespread and common species. Furthermore, different taxonomical treatises are inconsistent in their approach to habitat descriptions. Consequently, only three indices of habitat specificity could be used: vegetation type (Moll & Bossi 1984) and geological substratum type (Geological Survey 1970) occupied and altitudinal range. All the species listed as being restricted to specific ecotonal habitats were considered to occupy a single geology and vegetation type. Altitudinal range poses a problem in that widespread species on the flats have far smaller altitudinal ranges than localized species on mountain slopes. Consequently, I omitted altitude

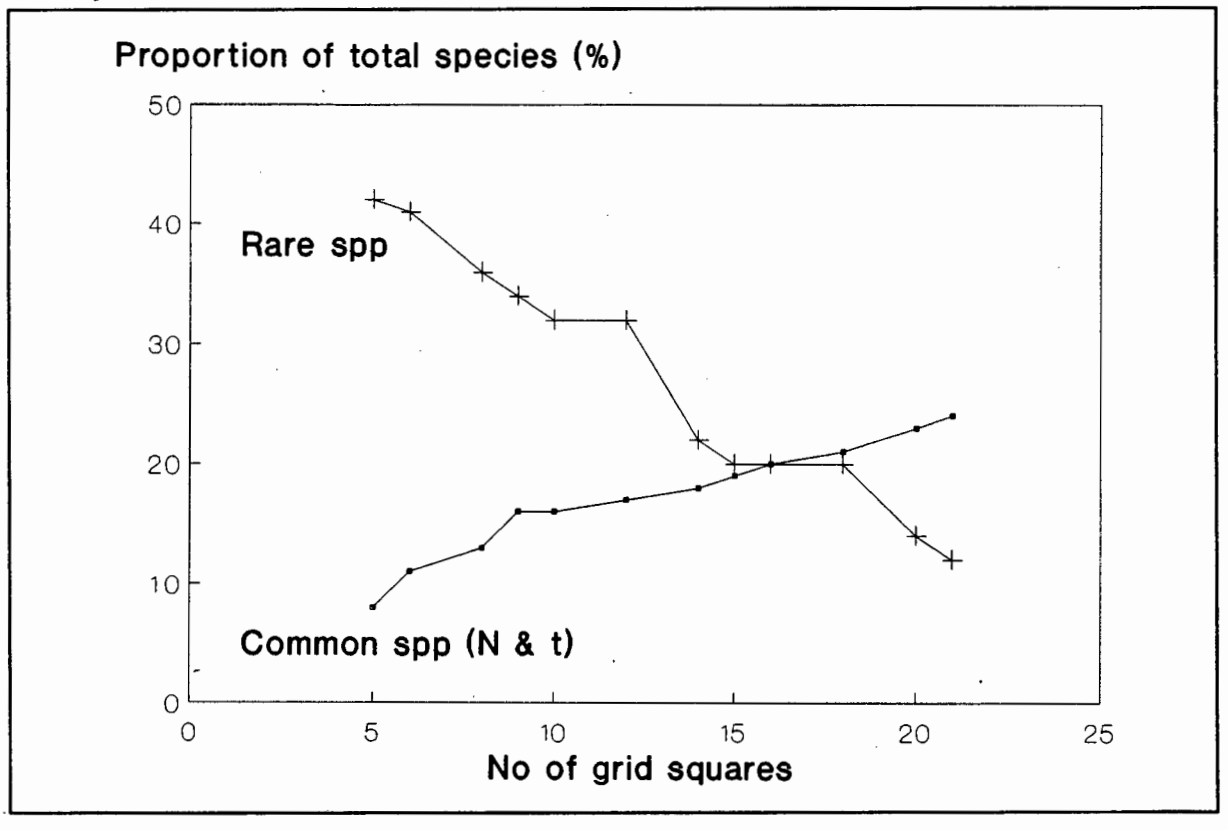

Fig. 2.2.1.3. The relationship between grid squares occupied and the proportion of critically rare *versus* non-Red-Data-Book species in the Proteaceae of the Cape Floristic Region.

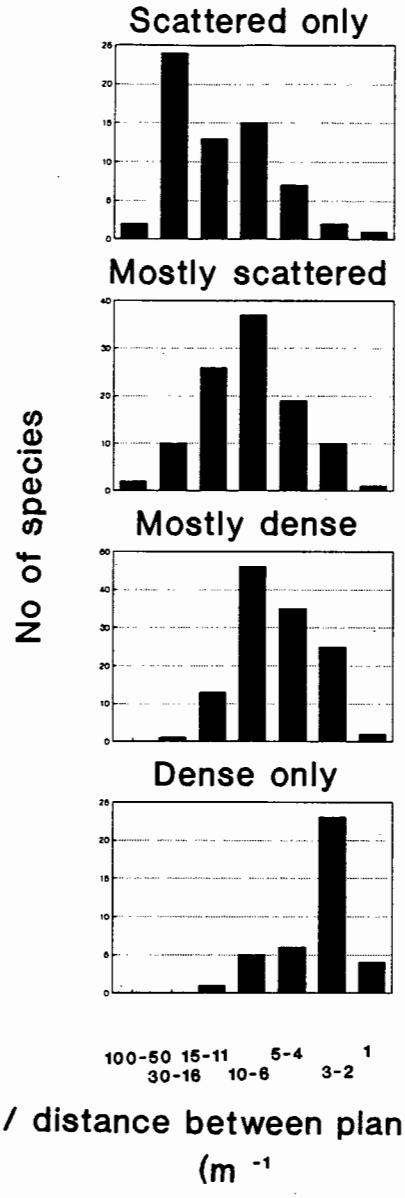

Fig. 2.2.1.4. Mean distance between plants in categories of population density.

and defined restricted habitat specificity as confined to both a single vegetation and geological type.

Rabinowitz categories of rarity for each constituent genus were compared with that of the family using a Chi-squared statistic. Similarly, the composition of Red Data Book categories, Red Data Book status changes and the proportion of range reduction were compared between Rabinowitz categories of rarity.

Species nomenclature follows Bond and Goldblatt (1984). Vegetation units are defined in Moll and Bossi (1984) and Cowling (in press). Red Data Book Status follows Tansley (1988). "Critically rare" is used (following Hall and Veldhuis (1985)) to designate those species assigned the Red Data Book status of "Rare". A listing of species composition within Rabinowitz categories of rarity is provided in Rebelo (1991).

RESULTS

Rabinowitz categories

The cut-off between rare and non-rare species, used to segregate species with "widespread" and "localized" distribution ranges, occurred at 18 grid squares (Fig. 2.2.1.3) - approximately 2800 km^2 or a square area with sides of 53 km - or 3.1 per cent of the area of the CFR. A significant difference in distance between plants exists between everywhere-sparse, usually-sparse, usually-dense, and always-dense species (Fig. 2.2.1.4).

The 331 species of Proteaceae were separated by distribution range into 198 widespread (W) and 133 localized (L) species, by habitat specificity into 97 broad (B) and 234 restricted (R) species, and, by population density into 266 somewhere-dense (D) and 65 everywhere-sparse (S) species (Table 2.2.1.1). Of the species with broad habitat tolerances, 80 per cent had widespread distribution ranges and dense populations. About 85 per cent of widespread species had some dense populations. Similarly, 69 per cent of localized species also had restricted habitat tolerances and 55 per cent of species with only sparse populations also had narrow distribution ranges and were

TABLE 2.2.1.1 Percentage of species in Rabinowitz rarity categories for the CFR and the UK

	Populations	Distribution: Widespread / Habitat: Broad	Distribution: Widespread / Habitat: Restricted	Distribution: Localized / Habitat: Broad	Distribution: Localized / Habitat: Restricted
CFR (N= 331)	Some dense	23.6	27.5	1.8	27.8
	All sparse	3.9	4.8	0.0	10.6
UK (N = 160)	Some dense	36.3	44.4	3.8	8.8
	All sparse	1.3	3.8	0.0	1.9

habitat-specific. As a consequence, three cells in the Rabinowtiz table (WBD, WRD and LRD) together contained 79 per cent of Proteaceae species (Table 2.2.1.1). Four cells (WBS, WRS, LBD and LBS) each contained less than six per cent of the species, one of which (LBD) was empty.

However, the three indices of rarity were not independent. Distribution range was significantly correlated with both population structure (Contingency coefficient $C = 0.139$, $P < 0.02$) and habitat specificity ($C = 0.408$, $P < 0.001$). However, the significant correlation with population structure is solely due to sparse species having a strong bias towards localized distributions ($X^2 = 5.20$, $P < 0.03$), with dense species showing no such relationship ($X^2 = 1.27$, $P > 0.5$). Habitat specificity and population structure were not correlated ($C = 0.100$, $P > 0.05$).

The use of continuous data yielded no correlation ($r = 0.0004$, $P > 0.05$) between geographical area and population density (as the inverse of distance between plants), even when log-transformed. However, geographical area and altitudinal range were strongly correlated (log transformed, $r = 0.305$, $P < 0.001$).

Taxonomic biases

The 12 genera did not equally reflect the status of Rabinowitz rarity in the family (Table 2.2.1.2). Thus the *Leucospermum* allies (*Diastella*, *Mimetes*, *Orothamnus* and *Vexatorella*) and *Paranomus* allies (*Paranomus*, *Spatalla* and *Sorocephalus*) differed significantly from the family ($X^2 = 11.0$, 10.1; $P < 0.05$, $df = 3$), containing too many localized species and too few habitat generalists. Consequently, they are under-represented in cells WBD and over-represented in cells LRD and LRS. *Serruria* had more species with sparse populations than expected ($X^2 = 10.3$; $P < 0.05$, $df = 3$), and consequently was over-represented in cell LRS. *Protea* had more species with widespread distributions and broad habitat tolerances than expected, and too few species with localized distributions, restricted habitat tolerances and sparse populations ($X^2 = 34.7$; $P < 0.05$, $df = 3$): consequently, it was over-represented in cell WBD and under-represented in cells LRD and LRS. *Leucospermum* and *Leucadendron* were representative of the family ($X^2 = 2.1$, 1.4; $P > 0.05$, $df = 3$).

The incidence of threatened and non-rare species among genera are not significantly different from that expected for the family ($X^2 = 5.9$, $X^2 = 5.9$, $P > 0.05$). However, critically rare species are significantly different among genera for that expected for the family ($X^2 = 18.0$, $P < 0.05$), being under-represented in *Protea* and over-represented in the *Leucopspermum* allies and *Paranomus* allies. The incidence of critically rare taxa among genera was, however, not significantly different from the expected incidence of localized, restricted and sparse species ($X^2 = 6.5$, 7.0 and 2.4, respectively, $P < 0.05$).

TABLE 2.2.1.2 Rabinowitz and Red Data Book status within genera of Proteaceae in the Cape Floristic Region.

	Rabinowitz categories of rarity								Red Data Book Status[1]						Number of spp
	WBD	WBS	WRD	WRS	LBD	LBS	LRD	LRS	X	E	V	R	t	N	
Orothamnus	0	0	0	0	1	-	0	0	0	0	0	1	0	0	1
Aulax	1	1	1	0	0	-	0	0	0	0	0	0	0	3	3
Vexatorella	0	0	3	0	0	-	2	0	0	0	0	1	0	4	5
Diastella	0	0	1	1	0	-	5	2	0	1	2	1	0	5	9
Sorocephalus	0	0	4	0	0	-	2	5	1	5	0	3	0	2	11
Mimetes	1	0	1	2	0	-	5	4	1	0	1	7	0	4	13
Paranomus	1	1	6	1	0	-	8	1	0	0	1	7	2	8	18
Spatalla	2	0	5	2	0	-	9	2	0	3	0	5	0	12	20
Leucospermum	9	2	14	0	2	-	16	3	0	1	6	5	9	25	46
Serruria	7	3	15	4	0	-	8	11	0	7	5	13	2	21	48
Protea	37	2	16	3	1	-	11	1	0	1	7	5	4	54	71
Leucadendron	20	4	25	3	2	-	26	6	1	15	7	12	9	42	86

[1] Codes defined in Table 2.2.1.3

Biases in allocating species status in Red Data Books (RDB)

All extinct species, and 67 and 45 per cent of endangered and vulnerable species, respectively, were geographically localized (Table 2.2.1.3). Some 87 per cent of critically rare species were localized. Of the 206 non-RDB species, 21 per cent were localized. It is not possible to guess what fraction of the threatened species might have been classified as critically rare had there been no anthropogenic threats present.

However, it is clear from ratios of critically rare to non-RDB species, that population density and habitat specificity were not considered as factors influencing RDB status for widespread species (WBD = 0.01; WBS = 0; WRD = 0.04), except when both factors operate together (WRS = 0.33). Amongst species with localized distributions and restricted habitat requirements, population density plays a role in determining RDB status (LRD = 0.94; LRS = 2.57).

The distribution of name changes within Rabinowitz categories, relative to the number of species in the category, is highly significant (X^2 = 23 (1980-1987), = 17 (1985-1987); $P < 0.005$, Table 2.2.1.3). Cell LRD had almost twice as many changes as expected. By contrast cells WBD and WRD had half and three-quarters as many changes as expected. The remaining cells contributed little to the trends. Of the total name changes over the three editions of the Red Data Books, 37 were better (the majority (20) from rare and indeterminate to non-RDB status) and 54 worse (one extinction, 16 to endangered, 15 to vulnerable, and 17 to rare) (Table 2.2.1.3). A single cell, LRD - with twice as many changes as expected - is responsible for the significant difference from expected for the change to better (X^2 = 15, $P < 0.005$). Three cells contributed markedly to the change to worse (X^2 = 16, $P < 0.005$): WBD had 0.25 times the expected value, and LRD and LRS had 1.5 and 1.8 times the expected value, respectively.

Half (16) of the endangered species are threatened by a reduction in distribution range (Table 2.2.1.3), mainly because of habitat destruction. The remainder either still have their extreme populations extant, or are threatened by factors reducing population numbers irrespective of geographical occurrence.

TABLE 2.2.1.3 Red Data Book (RDB) status and components of rarity for Rabinowitz codes.

	Number of species in category								(N)
	WBD	WBS	WRD	WRS	LBD	LBS	LRD	LRS	
Total number of species:	78	13	91	16	6	0	92	35	331
RDB Status: [1]									
X: Extinct	0	0	0	0	0	-	2	1	3
E: Endangered	1	1	9	0	1	-	14	7	33
V: Vulnerable	5	2	9	0	3	-	8	2	29
R: Critically rare	1	0	3	4	1	-	33	18	60
t: No longer listed	4	1	5	2	0	-	14	0	26
N: Never listed	67	9	65	10	1	-	21	7	180
RDB Summary:									
Threatened (X, E, V)	6	3	18	0	4	-	24	10	65
Critically rare (R)	1	0	3	4	1	-	33	18	60
Not listed (N, t)	71	10	70	12	1	-	35	7	206
RDB status changes:									
1981 [2] to 1989	8	4	18	4	3	-	44	9	90
1985 [3] to 1989	7	4	16	5	2	-	37	11	82
Both 1985 [1,2] & 1989 [2,3]	3	2	8	2	0	-	6	2	23
Reverted to 1981 [1,2,3]	1	1	2	0	0	-	4	2	10
Direction of name changes:									
Better	6	2	7	3	2	-	22	3	37
Neutral	0	1	1	1	0	-	1	0	4
Worse	3	2	12	1	1	-	25	10	54
Range reduction (% of occupied grid squares): [1]									
0	78 (E)	12	84.(5E)	16	3	-	82.(8E)	31.(3E)	306.(17E)
0.1-0.6	0	1 (E)	5.(2E)	0	2	-	1 (E)	0	9.(4E)
0.7-0.85	0	0	1 (E)	0	0	-	4.(X2E)	3.(3E)	8.(X6E)
>0.85	0	0	1 (E)	0	1 (E)	-	5.(3E)	1.(E)	8.(6E)
(Prop. of threatened with range reduction)	-	33%	39%	-	75%	-	42%	40%	38%

[1] Tansley 1988
[2] Hall & Veldhuis 1985
[3] Hall *et al.* 1980

DISCUSSION

Taxonomic biases

Most of the observed patterns of Rabinowitz rarity within the Proteaceae are predictable based on ecological traits within the genera (Rebelo & Bond 1991). Thus the *Leucospermum* and *Paranomus* allies are all myrmecochorous (with ant-dispersed fruit), insect-pollinated species. Although all *Leucospermum* species are myrmecochorous, most of the larger species are bird-pollinated and the smaller species insect-pollinated. *Leucadendron* alone comprises the entire range of seed-dispersal categories within the family, but is exclusively wind- and insect-pollinated. *Protea* comprises mainly serotinous (with canopy-stored seeds), bird-pollinated species, or resprouting, passive-dispersed fruit species, with very few insect-pollinated species.

Serruria is the only genus which does not behave as expected based on its ecological traits: rather than containing a preponderance of localized species, as expected from its exclusively myrmecochorous, insect-pollinated strategy, it contains too many sparse species without the expected pattern of localized geographical extent. It is also the only large genus which does not extend far to the east of the CFR. In addition, its major area of species richness is the Cape Peninsula and Malmesbury Flats, in contrast to most other genera which are more speciose in the mountains of the southwestern CFR.

Biases in assigning Red Data Book status

I expected that compilers of Red Data Book lists would differ more widely in their assignment of species with sparse populations to critically rare or non-rare categories than in their assignment of geographically localized species; and that this would be reflected in the rates of name changes. This is not so. Localized species with dense populations in restricted habitats elicited the most rapid name changes.

The incongruence between Red Data Book status and Rabinowitz categories is possibly due to a conflict in the use of population size and population extent in assigning RDB status. Thus species with large population sizes were variously categorized as critically rare or non-rare depending on whether emphasis was placed on geographical distribution or population size, this not being a problem for sparse species with their (perceived) low population numbers. However, it is easier to collect demographic and other autecological data for local endemics - so that the incidence of name changes may merely reflect a relatively greater increase in our knowledge of dense-population species relative to more widespread sparse species. Similarly, widespread, sparse species are less likely to be perceived as negatively impacted by local habitat destruction, whereas in the case of dense populations the threats can more readily be assessed.

Thus the total number of individuals appears to have been the underlying rationale in determining the categorization of species as critically rare, rather than the species' geographical occurrence, habitat specificity or population density.

Red Data and Rabinowitz rarity

If Red Data Book rarity status is to maintain scientific credulity then a consistent definition of rarity must be proposed. But do the Rabinowitz categories of rarity provide an adequate framework within which to define rarity?

A major shortcoming in the Rabinowitz approach is the indirect method of estimating the total number of individuals comprising the species. This is apparent in the diversity of indices which replace population density in the literature. Thus Ferrar (1989) used abundance (local population numbers) and Lahti *et al.* (1991) used dispersal ability and longevity of local populations, while ostensibly following Rabinowitz's classification.

It is possible for a species comprising 100 plants in three populations to occupy any of the eight Rabinowitz categories, which suggests that two further dimensions are apparently required to describe rarity. One of these is the total population size for the species. The use of total population size overcomes the problems of determining genetic neighbourhood distances and degree of isolation inherent in determining the number of populations and numbers of plants per population.

The other requirement is an index of what proportion of its habitat a habitat specialist/generalist occupies. This index is required because species' abundance varies on both the distribution and habitat dimensions. Thus densities usually peak near the centre of the species' distribution range (Brown 1984; Schoener 1987), and decline near the periphery, in addition to varying between habitats and within habitats. Although the population density component attempts to achieve this, it is currently

unsatisfactory. However, density data are not provided in taxonomical treatices and published vegetation surveys seldom provide a representative sample of the population structure of rare species, so that a more detailed classification may not be achievable from existing literature.

Although the approach to rarity has provided a framework for understanding rarity in the CFR, there are insufficient data to disentangle the factors influencing natural rarity in the region. Estimates of population numbers have only been made for the criticaly rare species (Tansley 1988), and published data do not allow habitat requirements to be classified at a level more detailed than that of the geological substratum or vegetation type occupied.

Lastly, seral variation in plant demography is a complicating factor that needs to be considered (Harper 1981; Harvey 1985). This is occassionally apparent in the CFR, where species are geared to a 10-30 year fire cycle (Cowling in press). For example, the Marsh Rose *Orothamnus zeyheri* was considered an endangered species until an accidental fire revealed that the adult plants were relatively short-lived and that the seed bank provided the buffer against longer-than-average fire cycles (Boucher 1981). I suspect, however, that relatively few cases of temporal rarity (in terms of numbers of individuals per area) related to seral stage occur in Fynbos vegetation in the CFR. This contrasts with Barro Colorado tropical forest where a large proportion (>50%) of rare plant species (occurring at densities below one individual per hectare) are more prominent in earlier seral stages (Hubbel & Foster 1986).

Patterns of rarity

The correlation between habitat specificity and geographical area was unexpected, since habitats in the CFR vary widely in size. For example, Mesic Mountain Fynbos (confined to the Table Mountain Sandstone Group) occurs over a vast area (16 000 km^2), whereas Lowland Fynbos on Tertiary sand (1 000 km^2) and Alexandria limestone Formation (2 000 km^2) cover relatively small areas (Moll & Bossi 1984, Fig. 2.2.1.1). Consequently, I expected many species with broad habitat tolerances to cover smaller areas than habitat specialists of Mountain Fynbos. Possibly habitat generalists are better able to spread between fragmented favourable habitats by establishing on alternative substrata. Habitat specialists, unable to colonize intervening habitats within fragmented (but geographically more-extensive) substrata, are therefore more likely to be restricted to contiguous areas. This might be especially true in Fynbos, which occurs on extremely nutrient-poor substrata, with plant dispersal mechanisms predominantly short-distanced and myrmecochorous (Slingsby & Bond 1985; Linder 1985; Westoby *et al.* 1990). Occasional crossings of unfavourable areas by fruit of habitat specialists are likely to result in significant founder effects and possibly speciation, except perhaps in species with long distance pollen transfer or fire-resprouters with their relatively long life-spans.

Why then is there no correlation between geographical distribution and habitat specificity in the United Kingdom (Rabinowitz *et al.* 1986)? I speculate that relative to the CFR the entire British flora consists of species which were capable of rapid recolonization of areas glaciated in the Pleistocene. That is, in relative terms the UK flora consists of habitat generalists with efficient seed dispersal. Consequently, speciation rates might be expected to be low and a suite of habitat specialists with short-distance seed dispersal has yet to evolve.

The major difference between rarity in the United Kingdom and that in the CFR (Table 2.2.1.1) is the high proportion of species confined to a restricted habitat with a local distribution in the CFR. This is not an artifact of our designation of widespread/narrow, since the example of a narrow geographic distribution provided in Rabinowitz *et al.* (1986) is 8 000 km^2 or three times the area used for the CFR. The use of a similar area to that used in the United

Kingdom would designate 61 per cent of Proteaceae species as localized, or, by extrapolation, two-thirds (3850) of all plant species endemic to the CFR. Those species with a localized distribution, broad habitat specificity and dense populations comprise the largest category of rarity in the CFR, equalling the number of species which are habitat specialists with widespread distribution ranges and dense populations.

As in the UK (Rabinowitz *et al.* 1986), there are no species with narrow distributions, sparse populations and broad habitat tolerances. I argued above that species with broad habitat tolerances almost invariably have widespread distribution ranges. I further suspect that such species will almost always be able to disperse into an ideal habitat, and therefore that habitat generalists will very seldom be encountered only in sparse populations. Thus in non-Mediterranean Europe and New Zealand most of the differences between common and rare species within regions of various scales can be interpreted in terms of local habitat availability (Field & Primack 1980; Hodgson 1986a; Lahti *et al.* 1991). By contrast, the majority of "European endemics" occur in southern Europe, within the Mediterranean region, and the patterns of their distribution cannot casually be explained in terms of habitat availability (Hodgson 1986b).

In addition, truly rare species (local, restricted and sparse) are five times higher in the CFR than in the United Kingdom, supporting the contention that the flora of the United Kingdom consists primarily of post-glacial opportunists.

Based on this comparison, I predict therefore, that there are only a few areas in the world where a correlation between habitat specificity and geographical distribution in plant species exists. These are the regions where large numbers of plant species have persisted throughout the Pleistocene climatic vissititudes whilst other species colonized the changing environments (Diamond & Hamilton 1982; Myers 1988). The large areas of the earth which have been colonized since the Pleistocene by 'weedy' species (with relatively high gene flow rates and therefore low speciation rates) should not show this relationship. Those plant species with low rates of spread, and thus high rates of speciation, are still largely confined to the Pleistocene refugia. It is thus possible to preserve 27 per cent of the higher plant species in just 0.2 per cent of the world's area (McNeely *et al.* 1990). If this is correct, then the numbers of plant species today is possibly a fraction of the pre-Pleistocene flora, and currently species-poor clades may contain survivors of clades which might be particularly speciose under prolonged, stable climatic conditions. Attempts at weighting species based on the numbers of extant species per clade (Vane-Wright *et al.* 1991) are therefore fraught with difficulties.

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Part 2. Causes of Rarity

2.2.2.

Ecological correlates of rarity in the Proteaceae of the Cape Floristic Region

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ECOLOGICAL CORRELATES OF RARITY IN THE PROTEACEAE OF THE CAPE FLORISTIC REGION

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The Cape Floristic Region (CFR) contains a high proportion of endemic species, many of which are listed in the Red Data Book as rare. We proposed a priori *correlates between ecological traits and rarity in the Proteaceae and tested these hypotheses against observed patterns. Species richness in guilds is strongly related to seed dispersal, pollination and regeneration. Thus classical theories of speciation appear adequate to explain the mode of origin and numbers of species in the CFR. We ascribe the apparent lack of such a relationship in temperate regions as the result of the relative youth of the floras and the paucity of species with low rates of spread.*

KEY WORDS: - Evolution - pollination - post-fire regeneration - Proteaceae - rarity - seed dispersal - speciation.

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INTRODUCTION

Rarity is of considerable applied and theoretical importance in conservation, and rare species justifiably form the focus of conservation efforts (Synge 1981, Kruckeberg & Rabinowitz 1985, Rabinowitz *et al.* 1986). An understanding of the causes and consequences of rarity will determine strategies for preserving rare taxa (Rabinowitz 1981).

However, rarity has seldom been rigorously defined. Part of the problem in defining rarity is that its origins are diverse (Kruckenberg & Rabinowitz 1985). Thus rare taxa have been considered as once more common *versus* never common (Stebbins 1942); as highly specialized *versus* highly localized (Mayr 1963); palaeoendemics *versus* neoendemics (Stebbins & Major 1965, Gentry 1986); and, anthropogenic *versus* natural (Cody 1986, Gentry 1986). A typology using geographical extent, habitat specificity and local population size, each long recognized as important components of rarity (Drury 1974), has been used to describe "seven forms" of rarity (Rabinowitz 1981; Kruckenberg & Rabinowitz 1985). Cody (1986) used these components of rarity to designate gamma-, beta- and alpha- rares, based on the component of species diversity in which the species is restricted.

The Cape Floristic Region (CFR) contains some 8600 plant species in an area of 90 000 km^2 (Bond & Goldblatt 1984), and ranks as the smallest of the six floristic Kingdoms (Takhtajan 1986). More importantly, it is characterized by a very high levels of endemicity (68% of species, 20% of genera, 5% of families), comparable to the richest tropical and temperate regions (Bond & Goldblatt 1984, Gentry 1986, Cowling & Holmes in press). A large proportion of these species (1500) are listed in the Red Data Book (Hall & Veldhuis 1985).

The conservation of this floral diversity requires an understanding of how this diversity orginated and is maintained. Unfortunately, this high diversity hampers understanding, since the flora of the CFR is far larger than the resources available to study it (Bond 1989).

In this paper we investigate the ecological correlates of rarity in the Proteaceae of the CFR, in an attempt to determine which factors influence rarity. Specifically, we determine to what degree current knowledge of the autecology and management requirements of the family contribute towards the effective conservation of rare species.

THE STUDY PLANTS

We selected the Proteaceae as probably the best known family in the region, taxonomically and ecologically, with distributional data available at a finer scale than for other families (Rebelo & Siegfried 1990). Specifically, the Proteaceae have been the focus of a detailed Red Data Book evaluation in 1985 by a panel of conservation officials, taxonomists and ecologists (Tansley 1988), so that there are no Uncertain (U) or Indeterminate (I) species. Furthermore, the distribution patterns of Proteaceae mirror the distribution patterns of other characteristic CFR plant families and major genera for which data are available at a quarter-degree (24 X 26 km) grid system (Rebelo & Siegfried 1990). The Proteaceae form a characteristic and often dominant, in terms of cover and stature, feature of Fynbos vegetation. The species range from small understorey shrubs to 3 m-tall overstorey shrubs. Only three of the 331 Proteaceae species and subspecies (hereafter referred to as species) considered herein are not endemic to the CFR. Thus considerations of rarity within the CFR will not be altered by studies of larger geographical regions.

METHODS

We classified Proteaceae species according to Rabinowitz rarity status (Figure 2.2.2.1) using published and unpublished data on species distribution, habitat specificity and population sizes as outlined in Rebelo (1991).

Biological attributes of the species were obtained from taxonomical treatises (Levyns 1970, Rourke, 1969, 1972, 1976, 1980, 1984a, 1984b, 1987, Williams 1972) and field experience (Rourke and Rebelo unpublished data). These include regeneration strategy (resprouting, non-resprouting), breeding system (dioecious, hermaphroditic), and modal canopy diameter of plants. The following parameters were estimated from field experience and discussions with taxonomists and horticulturalists: age to first flower (as six month-age classes), and number of plants per population (1, -10, -100, -1000, 10 000, > 100 000 individuals). There is considerable variation in some widespread species for these parameters, but hopefully they are in the correct order of magnitude. Species for which some data could not be obtained were assumed to be the same as taxonomically related, morphologically similar species occupying similar habitats.

Our approach has been to review the ecology of the family with regard to the traits which we feel might influence rarity or its components. The components of rarity were considered independently, thus habitat tolerance was regarded independently of the extent of the habitats. The null hypothesis, that species in each Rabinowitz category of rarity and its three components (distributional area, habitat specificity, population density) are distributed in the same proportions as the total species counts, was tested by chi-square and log-likelihood ratio (G^2) (Zar 1974). Data were further analysed for interactions among variables using log-linear models (GLIM: McCullagh & Nelder 1983), by assuming that the counts of species have a poisson distribution and Rabinowitz codes have a binomial distribution (with a logit link function).

Although we acknowledge that we have sampled all the species of Proteaceae in the CFR and that the probability of this is unity (so that statistical probabilities are meaningless), the existing situation is a sample of those which might have arisen given the *a priori* hypotheses considered. These hypotheses are applicable to the flora as a whole, and could be tested on different families in the CFR, on the Proteaceae in Australia, *etc.*, thus justifying a statistical treatment. The models are assumed to only explain a proportion of the variation, the remainder being due to unmeasured and unknown processes that generated the variability.

Species nomenclature follows Bond and Goldblatt (1984). Vegetation units are defined in Moll and Bossi (1984) and Cowling (in press). Red Data Book Status follows Tansley (1988). A listing of species composition within Rabinowitz categories of rarity are provided in Rebelo (1991).

ECOLOGICAL CORRELATES OF RARITY: AN *A PRIORI* REVIEW.

The Proteaceae do not fill all possible ecological niches equally (Table 2.2.2.1). For instance there are no dioecious, bird- or mammal-pollinated species, no hermaphroditic, wind-pollinated species, nor are there any resprouting, wind-pollinated species. Thus out of 48 permutations of regeneration strategy, seed dispersal, pollination syndrome, and breeding system, only 20 (42%) are filled. The unfilled categories listed above account for 21 (44%) of the empty permutations. Some 83 per cent of Proteaceae species occur in 7 permutations. Some 110 species (33% of the family) occupy a single permutation (killed by fire, myrmecochorous, insect-pollinated and hermaphroditic), the majority (54) of these species

Distribution range	Widespread (W)		Localized (L)	
Habitat requirements	Broad (B)	Restricted (R)	Broad (B)	Restricted (R)
Population density Somewhere dense (D)	WBD	WRD	LBD	LRD
Everywhere sparse (S)	WBS	WRS	LBS	LRS

Figure 2.2.2.1. Rabinowitz categories of rarity and codes used in the text.

Table 2.2.2.1. The number of species in guilds of the Proteaceae in the CFR. The predicted sequence of species richness is based on a consideration of persistence (regeneration mode) and gene flow (seed dispersal and pollination syndrome) on the rate of speciation.

Number of species [1]	Regener -ation mode [2]	Seed dispersal syndrome [3]	Pollina tion syndrome [4]	Breeding system	Predicted sequence of spp. per guild [5]	log Geogr. area [6] (X+SD) (grid squares)	log density [6] (X+SD) (plants per m)
110	kill	myrm	inst	herm	1a	1.2±0.7 A	0.9±0.4
36	kill	sero	inst	dioc	3a	1.6±0.6 ab	0.8±0.3 B
35	kill	sero	bird	herm	4	1.9±0.7 abC	1.0±0.4 ab
34	kill	myrm	bird	herm	2	1.3±0.6 B	0.8±0.3 A
29	kill	pass	inst	dioc			
19	resp	myrm	inst	herm	5	1.4±0.6 c	1.0±0.3 a
11	resp	pass	bird	herm			
7	resp	myrm	bird	herm	6	1.3±1.2	0.9±0.4 b
7	kill	sero	mamm	herm			
6	kill	sero	wind	dioc			
5	resp	sero	inst	dioc	7	2.1±1.0 ab	1.0±0.2
5	resp	pass	inst	dioc			
4	kill	myrm	inst	dioc	1a		
4	kill	myrm	wind	dioc			
4	kill	pass	mamm	herm			
4	resp	pass	mamm	herm			
4	resp	sero	bird	herm	8	1.7±1.1	1.2±0.2 ab
3	kill	sero	inst	herm	3a		
3	kill	pass	bird	herm			
1	kill	myrm	mamm	herm			

[1] Kill = obligate reseeders killed by fire; resp = resprouting from boles or aerial/underground stems.
[2] Myrm = myrmecochorous; sero = serotinous; pass = passive.
[3] Inst = insect; mamm = mammal.
[4] Herm = hermaphroditic; dioc = dioecious.
[5] Significant differences ($P < 0.05$) between like capital *versus* lower case letters.
[6] For testing hypotheses passive seed dispersal and mammal and wind pollination are exluded.

first flowering between 36 and 54 months of age.

Seed dispersal: predictions

There are three major seed-dispersal/storage strategies in the Proteaceae of the CFR (Rebelo & Rourke 1986). Fruit are stored in fire-proof heads (serotiny) in all *Aulax*, 72 per cent of *Protea* and 51 per cent of *Leucadendron* species (Bond 1985, Le Maitre 1987). Some 28 and 40 per cent of *Protea* and *Leucadendron* species, which have fruit with no known specific dispersal/burial agent are presumably soil-stored (hereafter referred to as passive dispersal) (Rebelo & Rourke 1986). The remaining species of Proteaceae have fruit which are presumed to be buried by ants (myrmecochory) as they have a conspicuous elaiosome, or ant-fruit (Bond and Slingsby 1983, 1984a, b, Slingsby and Bond 1985).

Dispersal distances for serotinous species may exceed several hundred metres (Bond 1988). However, it is likely that those species with fruit which are winged (*Leucadendron* sections *Alata*, *Brunneobracteata* and *Compressa*), hairy (*Protea*, *Leucadendron* sections *Nervosum* and *Villosa*) and have parachutes (*Leucadendron* section *Leucadendron*) disperse much further than wingless species (*Leucadendron* section *Trigona*) (Bond 1988). By contrast species with ant-dispersed fruit are seldom considered to move more than a few metres (Bond & Slingsby 1984b, Slingsby & Bond 1985), despite some species having conspicuously hairy fruit. Of the 31

Leucadendron species with passive dispersal 20 (in sections *Membranacea* and *Nucifera*) have large, bi-ovoid nuts [which are heavily predated and possibly cached by rodents (Rebelo & Rourke 1986), although there are no known seed-caching rodents in Fynbos (Bond & Breytenbach 1985)], six are rounded or slightly trigonal with a ridged margin (sections *Cuneata* and *Ventricosa*), and five (section *Villosa*) are small and hairy (Williams 1972). Thus only the latter probably move any appreciable distance from the plants, but their release in mature vegetation probably limits dispersal distances to a few metres (Bond 1989).

Thus we expect that serotinous species should have the largest dispersal distances and therefore the widest distribution ranges, whereas passive and myrmecochorous species should have small distribution ranges. However, given sufficient time, even species with small dispersal distances could become widespread. Larger seed dispersal distances also imply greater gene flow, and speciation rates are likely to be lower than in species with seeds that have shorter dispersal distances. Therefore, we expect there to be more, localized myrmecochorous species and fewer, widespread serotinous species.

Species with restricted habitat tolerances might benefit by having short seed-dispersal distances. Species with broad habitat tolerances should not be similarly limited. Dispersal distance otherwise appears not to have any predictable relationship with habitat specificity. Seed dispersal seems to have no link with population density.

Seed dispersal: results

To a large extent, the data support predictions based on what is known of differences among seed-dispersal guilds. As expected from predictions on speciation rates, myrmecochorous species (179) were more numerous than serotinous species (96). However, species with passive-dispersed fruit were the least numerous (56 species)

As predicted, serotinous species were more widespread and myrmecochorous species more localized than expected for the family (Table 2.2.2.2). Species with passive seed dispersal had no significant differences in geographical range relative to the family, although there was a significant difference when only passive-dispersed, obligate reseeding (non-resprouting) species were considered ($P < 0.001$, $X^2 = 14.66$). About 66 per cent of serotinous species had broad habitats, whereas myrmecochorous species occurred more in restricted habitats than expected (Table 2.2.2.2). We did not predict this last result, but it follows from the strong correlation between habitat specificity and distributional range. Myrmecochorous species comprised sparse populations more frequently than expected and significantly more serotinous species occurred in dense populations than expected (Table 2.2.2.2).

Three cells of the Rabinowitz table contributed extensively to the significant difference with overall expected values: WBD which had more serotinous and fewer myrmecochorous species, LRD which had fewer serotinous species, and, LRS which had more myrmecochorous and fewer serotinous species than expected (Table 2.2.2.2).

Distribution ranges for sections within *Leucadendron* displayed the predicted trends based on seed-dispersal strategy, but no differences were significant (log-transformed, t-test, $P > 0.2$ for all comparisons). Mean values (in grid squares, converted from mean of log-transformed data for sections) among serotinous species were: *Trigona* 25.7, *Alata* 49.0, *Compressa* 57.5, *Villosa* 57.5, and *Leucadendron* 104.7; and among passive species were: *Villosa* 44.7, *Membranacea/Nucifera* 20.4, and *Ventricosa/Cuneata* 11.7. Contrary to expectations, mean geographical ranges for serotinous *Leucadendron* species were not always larger than for passively-dispersed species, specifically section *Villosa* (passive, hairy) had distribution ranges equivalent to section *Alata* (serotinous, winged), although the pattern held within section *Villosa* (passive *versus* serotinous).

Table 2.2.2.2 Tests of guild composition for Rabinowitz codes relative to the total. In all cases, except one, X^2 values, G^2 values and X^2 for collapsed tables gave similar P values.

	Number of taxa in category								X^2			
	WBD	WBS	WRD	WRS	LBD	LBS	LRD	LRS	Over-all	Geographical distribution	Habitat specificity	Population density
Total:	78	13	91	16	6	0	92	35				
Seed dispersal:									47.6 **	21.0 **	31.5 **	9.1 *
Ant	21	6	52	10	3	-	58	29	18.0 *	7.6 *	13.5 **	3.9 *
Serotiny	40	5	28	2	1	-	17	3	24.2 **	13.4 **	16.1 **	4.9 *
Other	17	2	11	4	2	-	17	3	-. NS	0.0 NS	1.8 NS	0.4 NS
Pollination:									17.6 *	8.2 *	18.6 **	7.4 +
Wind	4	0	2	0	1	-	3	0	-. NS	0.0 NS	2.1 NS	2.4 NS
Insect	32	10	62	11	3	-	65	28	9.3 NS	2.5 NS	6.5 *	2.0 NS
Bird	34	3	23	4	2	-	21	7	8.3 NS	2.7 NS	6.7 *	1.2 NS
Rodent	8	0	4	1	0	-	3	0	-. NS	3.1 NS	3.3 NS	1.8 NS
Regeneration:									27.2 **	6.0 *	17.5 **	1.6 NS
Reseed	59	6	80	12	3	-	84	32	4.8 NS	1.0 NS	2.9 NS	0.3
Resprout	19	7	11	4	3	-	8	3	-.	5.0 **	14.6 **	1.3
Breeding:									3.5 NS	0.2 NS	0.3 NS	1.0 NS
Cosexual	57	8	65	13	4	-	66	29	1.0 NS	0.1 NS	0.1 NS	0.3 NS
dioecious	21	5	26	3	2	-	26	6	2.7 NS	0.1 NS	0.2 NS	0.7 NS

* = $P < 0.05$; ** = $P < 0.001$; NS = $P > 0.5$;
- = expected values too low for valid analysis;
+ = G^2 value with $P < 0.05$, X^2 value with $P > 0.5$

Pollination: predictions

Mode of pollination does not influence species distribution or rarity directly. Although there is no direct evidence, birds are probably efficient dispersers of pollen in terms of distances moved, whereas rodents, wind and, perhaps, most insects do not move pollen as far (Rebelo 1987). Thus gene flow distances would be greater for bird than for other pollination syndromes. If this pollen flow overcomes genetic drift, there should be less speciation among bird-pollinated taxa and we might expect these taxa to be more widespread. Similarly, as we might expect more genetic drift, founder effects and, therefore, speciation among other pollination syndromes, these species might be more localized. We therefore expect there to be fewer bird-pollinated species and more insect-pollinated species. However, this is confounded by the wide variety of insect pollination syndromes, even though most Proteaceae rely on beetles for pollination (Collins & Rebelo 1987, Hatting & Giliomee 1989).

Among wind-pollinated species, classical theory predicts that populations must be dense because pollen transfer is inefficient over larger distances (Faegri & vd Pijl 1979). If this is accepted as correct, then wind-pollinated species should experience considerable resistance to establishing new populations in fragmented (unless linear) habitats. We further predict that very short-distance seed dispersal would help to build up population densities: i.e. wind-pollinated species occurring within fragmented habitats should have passive or myrmecochorous fruit. We therefore predict that wind-pollinated species should be speciose and have localized distribution ranges.

Mammal pollination is reported in the literature to be an anomaly within the family, apparently being confined to species with small, localized populations and small distributional ranges (Wiens *et al.* 1983).

We could not predict any relationship between pollination and habitat specificity.

For small populations, self-infertility might be a disadvantage, but sufficient data on fertility are not available for the Proteaceae (Horn 1962, Collins & Rebelo 1987). It is thus not possible to establish a relationship between pollination and population density. Wind pollination is a special case in which sparse species might be at a tremendous disadvantage (Koutnik 1987, Rebelo & Jarman 1987) relative to bird or large-insect pollination syndromes, if classical theories (Faegri & vd Pijl 1979) of wind pollination are held.

Significantly more bird-pollinated species and fewer insect-pollinated species than expected had broad habitat tolerances (Table 2.2.2.2). In cell WBD of the Rabinowitz table, insect pollination was under-represented and bird and mammal pollination were over-represented. No other cells contributed significantly to the X^2 value. There was an overall difference from expected for geographical area, but this was not reflected in any of the individual pollination syndromes. No significant results existed for population density (Table 2.2.2.2).

Pollination: results

All 10 wind-pollinated species occurred in dense populations, but sample sizes were too small for statistical comparison. Geographical area of wind-pollinated species was not significantly different from that of other syndromes (t-test, log-transformed data, $P > 0.05$) and there were far fewer species than predicted. Obviously our assumptions regarding wind pollination are inadequate.

The geographical area of mammal-pollinated species (43.7 grid squares, mean converted from log-transformed data) was not significantly different (t-test, $P > 0.05$) from wind (27.5), insect (20.4), or bird (43.7) pollination syndromes. However, half of mammal-pollinated species occupied between 51 and 100 grid squares in contrast to only 16 per cent for the family ($X^2 = 8.2$, $P < 0.01$). Population size for mammal-pollinated species was no different from that expected for the family ($X^2 = 1.1$, $P > 0.9$). Since 15 of the 16 mammal-pollinated species belong to *Protea*, a bias within *Protea* might confound the results. However, within *Protea* no significant difference in geographical range ($t = 1.41$, $P > 0.5$) or population size ($X^2 = 1.54$, $P > 0.05$) was found between mammal and bird-pollinated ($n = 54$) species.

Regeneration: predictions

There are two main strategies employed in the Proteaceae to survive fire: adult plants either may survive a fire (resprouters) or be killed by fire (obligate reseeders, hereafter referred to as reseeders). Resprouting species comprise three major strategies: underground lignotubers (most genera); underground rhizomes (*Protea*); and, aerial subcortical buds protected by a thick bark (*Protea nitida*) (Anon 1990). A few additional species escape fires by growing above the surrounding vegetation or occurring in fire-safe habitats (*viz.* rocky outcrops and screes) - the last are not considered further. Resprouters are better persisters in a habitat and therefore are less susceptible to local extinction. This contrasts especially to reseeding, serotinous species which are prone to local extinction by aseasonal fires (Bond 1985, van Wilgen & Viviers 1985). A portion of the seed crop might be carried over through successive fires in species with soil-stored seeds, conferring a small degree of persistence. However, this would presumably be a small fraction of the adult population, in contrast to resprouters, where between 50 and 100 per cent of adults typically survive successive fires (pers. obs).

Because resprouters have a lower seed production than reseeders of similar size (Carpenter & Recher 1978), having to invest some resources in survival

rather than seed production, they should disperse more slowly than reseeders. However, resprouters also have longer generation times, comprising several fire cycles. Thus these plants escape the selection pressures operating after every fire on seedlings of non-resprouting species. Consequently, they should be less prone to genetic drift and therefore speciation. Because of their high persistence and low speciation rates, resprouting species should on average be older than reseeding species. No data on extinction or speciation rates within the Proteaceae are available. We therefore have conflicting predictions: the low seed production suggests that the distribution ranges for resprouters should be less than that of reseeders. However, the high persistence of resprouters and their greater age suggests that colonized distribution ranges are unlikely to be ceded and that distributions should be larger than for reseeders.

No obvious relationships can be predicted between resprouting and habitat specificity, although resprouters may be able to sustain populations in marginal habitats for long periods if climatic conditions occasionally allow recruitment. Similarly, since resprouters are continuously present in the environment, not having the post-fire absence of plants as experienced by reseeders, predation and infection levels may be higher: consequently, resprouters may occur at lower population densities than reseeders.

Regeneration: results

Significantly more resprouting species (75 per cent) than expected had widespread distribution ranges (Table 2.2.2.2). There was little difference from expected for reseeding species. This was contrary to our expectations based on a relationship between seed numbers and dispersal and suggests that persistence or age may compensate for the reduced seed output of resprouting species in terms of dispersal potential.

Resprouters exhibited broad habitat tolerance significantly more frequently than expected (Table 2.2.2.2). In the Rabinowitz table, non-resprouters occupy all cells as expected and, although the sample sizes are too small to statisticaly resolve the patterns exibited by resprouters, they appear to be over-represented in cell WBS and under-represented in cell LRD.

As predicted, resprouters were a minority (55 species) relative to reseeders (276 species). Similarly, resprouters occurred in sparser populations ($t = 3.66$, $P < 0.001$), with a mean density of 1.0 plants per metre (converted from log-transformed data) *versus* 1.5 plants per metre for reseeders.

Breeding system: predictions

Aulax and *Leucadendron* are both dioecious genera, accounting for 27 per cent of Proteaceae species (Steiner 1987, 1988). We cannot ascribe any role for dioecy in determining the rarity status of species. Some dioecious species have sexual dimorphism, which it has been argued may allow the sexes to partition available resources or habitat, thus effectively increasing population sizes (Cox 1981). Both genera appear to have far higher seed production per female than cosexual genera in the Proteaceae, but seed production as a proportion of the total number of flowers produced is similar between dioecious and cosexual species (Rebelo & Rourke 1986).

Dioecious species might be disadvantaged at very low population densities. No relationship between breeding system and habitat specificity or geographical distribution is theoretically apparent.

Breeding system: results

There were no significant differences from expected values for dioeceous or cosexual species between widespread *vs* localized distributions, broad *vs* restricted habitat tolerances or dense *vs* sparse population sizes or for the Rabinowitz table (Table 2.2.2.2). Specifically, dioecious species were not significantly under-represented for sparse populations.

Table 2.2.2.3 Mean (+SD) plant diameter and age to first flower in different categories of rarity within the Proteaceae of the Cape Floristic Region.

		Plant diameter (mm)	Age to first flower (months)
Geographical distribution	Widespread	1310.4 ± 1046.5	48.6 ± 18.5
	Localized	1016.9 ± 894.7	49.2 ± 21.8
Habitat specificity	Broad	1424.7 ± 1183.9	47.7 ± 17.5
	Restricted	1096.2 ± 893.5	49.4 ± 20.8
Population density	Dense	990.6 ± 950.2	48.2 ± 19.4
	Sparse	1240.8 ± 1004.0	51.8 ± 21.8

Age to first flowering: predictions

Species with rapid maturation times should be less susceptible to extinction by occasional short-rotation fires (Van Wilgen & Viviers 1985). However, faster maturation will not favour more rapid population spread, because regeneration is linked to the fire cycle and slower maturing species therefore have the same potential for spread. The only inference to be made is that species with very slow maturation times should be severely disadvantaged by occasional short-rotation fires. These species should therefore have fragmented distribution ranges, occurring mainly in relatively fire-safe habitats where occasional fires still allow recruitment (forest edges, rocky outcrops, cliff faces, as tall plants in short vegetation). However, data on meta-population structure do not exist for the Proteaceae, and this issue cannot be explored at this stage.

Species occurring in dense populations may benefit from rapid maturation if it is coupled with a rapid growth rate. Conversely, slow growing, late maturing species are unlikely to occur in dense populations, unless they are superior competitors or resprouters. Without additional data on competive ability relative to surrounding species, no predictions can be made for late maturing species.

Age to first flowering: results

No significant differences between Rabinowitz categories of rarity or the three components of rarity were apparent for age to first flower (Table 2.2.2.3: t-test, $P > 0.05$).

Size: predictions

Leaf size in the Proteaceae is allometrically scaled to rate of branching, number of inflorescences, inflorescence size and possibly biomass production and reproductive output (Bond & Midgley 1988, Midgley & Bond 1989, Le Maitre & Midgley in press). Plant size may be negatively correlated with productivity and possibly with ability to reproduce in the late succession (Tilman 1988).

Because larger plants occupy more area, species comprising large plants should be more widespread, more habitat tolerant and should form denser populations (per unit area) than smaller plants for equivalent population sizes to be maintained. Smaller plants should be neutral to all these patterns, but through competitive exclusion by bigger plants might be forced into being less dense and occupying more restricted habitats. As a consequence of these factors, there should be fewer species with larger plants and more with smaller plants.

Size: results

No significant differences between Rabinowitz categories of rarity or the three components of rarity were apparent for plant size (Table 2.2.2.3: t-test, $P > 0.05$). As predicted, there are fewer species of larger plants (Figure 2.2.2.2).

Interactions between ecological variables: predictions

Interactions among ecological variables are hard to predict, and it is almost impossible to determine the combined effects of three or more variables. The following predictions were the most obvious.

Interactions between wind and dioecy should result in few species with sparse populations. In reality, all wind-pollinated Proteaceae species are dioecious, and all occur in dense populations.

Although species with long maturation times will be disadvantaged by frequent fires, resprouters will be resilient to this as failure to recruit for several fire cycles may not adversely affect population sizes. Indeed, resprouters may require a long period to sexual maturity while resources are sunk into fire protection (Anon 1990). We therefore predict that resprouters will have longer maturation periods than reseeders.

Interactions between ecological variables: results

Resprouters start flowering at an average age of 61+20 months (+SD), whereas reseeders start flowering significantly earlier (t-test = 5.00, $P < 0.001$) at 47+19 months. This is due both to resprouting species first flowering later than reseeders and most reseeding species flowering well before 60 months. Amongst reprouters only four species flower before 42 months, compared to 116 reseeding species ($X^2 = 15.2$, $P < 0.001$). Similarly, of the 75 species flowering after 66 months, 34 are resprouters ($X^2 = 44.3$, $P < 0.001$).

We predict that persisters with large gene flow distances (resprouting, serotinous, bird-

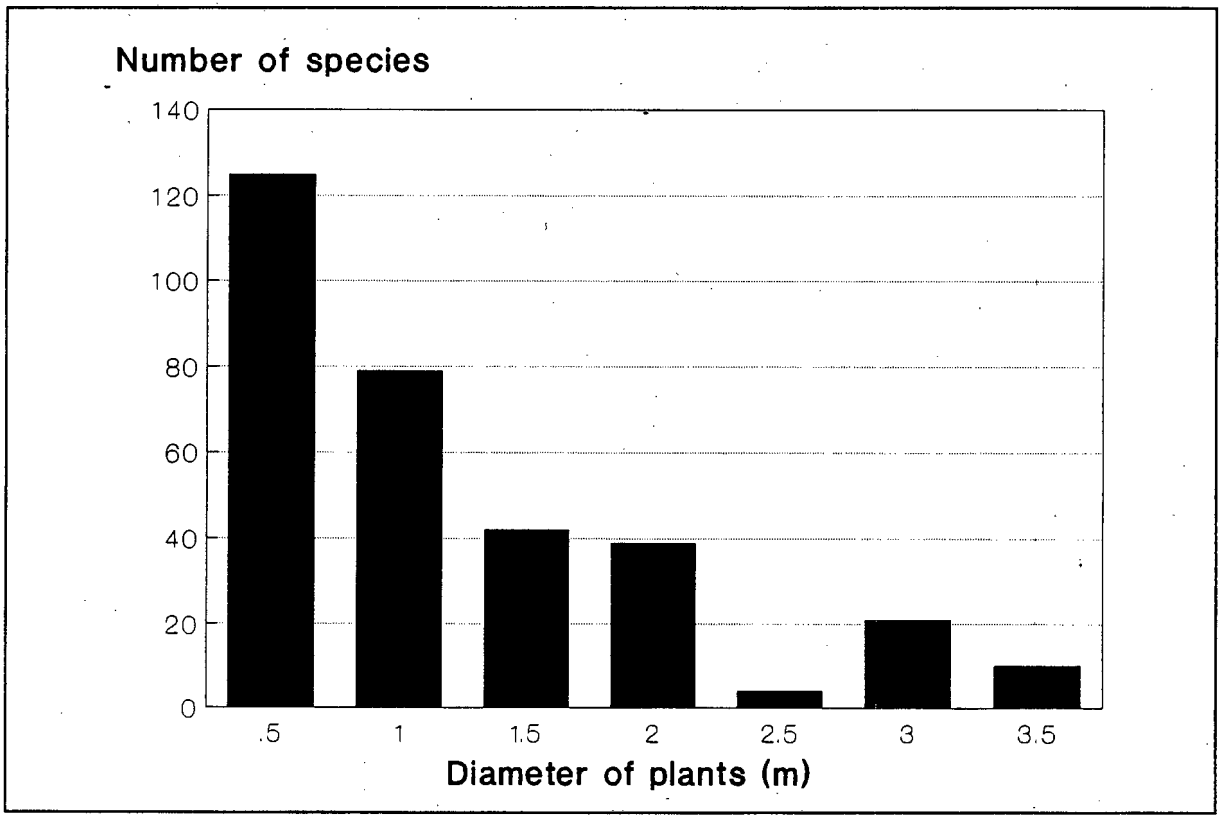

Figure 2.2.2.2. Plot of size of plant versus number of species

pollinated) will have larger geographical distributions and far fewer species than obligate reseeders with short distance gene flow (reseeding, myrmecochorous, insect-pollinated). Intermediate combinations of regeneration, seed dispersal and pollination syndrome (here listed in order of importance) should be intermediate in numbers and distribution range. We are unable to provide any explanation as to whether hermaphroditic or dioecious species should be more speciose.

The predicted sequence of the interaction between regeneration strategy, seed dispersal strategy and pollination syndrome yielded the species sequence listed in Table 2.2.2.1. The match between the predicted sequence and the obtained sequence is remarkable (Kendal rank correlation coefficient $r = 0.86$, $P < 0.001$). In terms of geographical area covered, however, the predicted sequence is not correct. Instead, seed dispersal is the major correlate with geographical area, with regeneration mode and pollination syndrome playing little role. All significant differences for log-transformed geographical area are between serotiny *versus* myrmecochorous combinations (Table 2.2.2.1). In terms of population density, regeneration strategy and pollination syndrome are weak determinants of the sequence, but few differences in mean density are significant (Table 2.2.2.1).

Results of GLIM suggest that few interactions between variables existed. Some 96 per cent of the deviance in the number of species was explained by a model containing interactions between seed dispersal (S) and each of pollination (P), breeding system (B) and age (A) and an interaction between regeneration strategy (R) and age (*i.e.* model: SP, SB, SA, RA). The interactions accounted for some 89 per cent of the deviance: thus relative contributions between factors are close to this value and approximate 90% for seed dispersal, 88% for breeding system, 87% for pollination and age and 85 % for regeneration. Two other marginal two-factor interactions, PA and AG, which were significant ($P < 0.05$) relative to the saturated single-effect model, were correlated to other interaction effects in the model above and therefore do not feature in the model. The above model predicted species number remarkably well: no guilds had residuals exceeding 2.0). Four cells had residuals exceeding 1.5: the model predicted fewer species than exist in two guilds (reseeding, passive-dispersed, mammal-pollinated, hermaphroditic, late-flowering [first flowering before 3.5 years] and resprouting, passive-dispersed, bird-pollinated, hermaphroditic, mature flowering [between 3.5 and 5.5 years]); and more species in two guilds [reseeder, passive-dispersed, mammal-pollinated, hermaphroditic, mature-flowering and reseeding, serotinous, bird-pollinated, hermaphroditic, late-flowering (after 5.5 years)]. With the exception of the last case, these comprise species with a combination of mammal pollination and passive seed dispersal: *i.e.* mammal-pollinated *Protea* species.

The extremely high proportion of the deviance explained by the model, suggests that species number is very strongly related to the measured variables reflecting gene flow (pollination syndrome and seed dispersal) and persistence (age and regeneration strategy). The interactions suggest that regeneration strategy is related to age to first flowering (as predicted) and that furthermore the effect of seed dispersal is influenced by age, pollination and breeding system.

In the GLIM analysis of distribution range data only 53 per cent of the deviance is explained by a seed dispersal, regeneration strategy and an interaction between the two variables (*i.e.* model: SR). Pollination syndrome contributed significantly on its own (as a marginal main effect), but not when considered in a model together with seed dispersal. A model incorporating regeneration strategy and an interaction between pollination syndrome and seed dispersal (*i.e.* model R, SP) was also marginally significant, but is rejected as less parsimonious.

Thus distribution ranges of Proteaceae species are weakly explained by an interaction between the two variables predicted to determine distribution range. Too few (residual = 2.8) species of the

reseeder, serotinous, insect-pollinated, hermaphroditic, medium age species were widespread (both species are localized).

In the GLIM analysis of the habitat data some 62 per cent of the deviance is explained by a model incorporating seed dispersal, resprouting strategy, pollination syndrome and age to first flower (*i.e.* model R, S, P, A). Marginal main effects occurred for S, P and R (in order of importance), and partial main effects by S, R and A. No significant two-factor interactions were significant, nor were there alternative models. Thus habitat specificity is related to seed dispersal and regeneration strategy, but also to pollination syndrome and age to first flower. No interaction effects exist.

In the GLIM analysis of the density data two equivalent models accounted for 20 per cent of the deviance. These were simple models comprising only pollination syndrome and seed dispersal (*i.e.* models P and S). A model with both seed dispersal and pollination syndrome showed the two variables to inter-correlated. There are thus no interactions between variables correlated with density, which are poor predictors of density.

DISCUSSION

Rarity and speciation

The classical theory of speciation bestows upon gene flow and genetic integrity a central role in speciation (Mayr 1969, Raven 1980, Linder 1985). However, gene flow in plants is spatially too limited to be of significance in maintaining species integrity, and is therefore unlikely to play a causal role in the speciation process (Ehrlich & Raven 1969). Thus Linder (1985) used Cape Floristic Region examples and "ecological theory" to suggest that species integrity is maintained by stabilizing selection and not gene flow, and that speciation is a consequence of adaptation to different habitats by populations originating from a single ancestral population.

However, our results clearly show that merely a consideration of gene dispersal (by seeds) and persistence (by resprouting) accurately predict species richness in the CFR, irrespective of both habitat and historical considerations and in spite of rates of gene flow perhaps lower than for most other geographical regions (Slingsby & Bond 1985, Westoby *et al.* 1990). We are unable to account for this result, except by assuming that the classical theory of speciation, with emphasis on barriers to gene flow, is sufficient to account for speciation in the CFR.

A component of gene flow that is often dismissed in the literature is that of seed dispersal (Ehrlich & Raven 1969). Thus while seeds can move large distances to establish new colonies, seed dispersal to existing colonies may be effectively excluded by seedling competition with locally adapted older cohorts. However, in Fynbos vegetation fire intervals of between 15 and 30 years effectively limits regeneration to a single post-fire cohort, so that seeds from distant populations may be better able to establish even within existing locally-adapted populations. This feature of Fynbos regeneration is reflected in its high susceptibility to invasion by alien plant invaders (Macdonald 1984).

Specifically two possible trends are apparent in Fynbos which require further investigation. Firstly, it appears that low seed production in resprouting species, due to the need to invest in fire-protection processes, which should result in a lower population density and a lower potential rate of spread, is more than compensated for by the higher persistence of populations, so that resprouters tend to be less speciose and more widespread than non-resprouting relatives. Indeed, persistence is regarded as an implicit criterion of fitness in many population dynamic models (Rabinowitz *et al.* 1984)

Secondly, by contrast, serotinous species are highly susceptible to local extinction by too frequent fires (Bond 1985), much more so than myrmecochorous species for which a proportion of seeds may theoretically survive several fire cycles (especially if inter-fire periods are short) before germinating. And yet serotinous species have not speciated to form allopatric species, but form

isolated populations over large geographical areas. It appears therefore that serotinous species may utilize efficient seed dispersal to overcome the high extinction rates, and that this widespread gene flow may account for the low speciation rates. It appears therefore that a holistic viewpoint of rates of gene flow must take into account a long-term perspective in which populations may be mobile within the landscape.

There is however, a link between speciation and habitat diversity within the CFR. Species with a broad habitat tolerance are invariably widespread. Serotinous and resprouting species contain significantly more habitat generalists than expected for the family. Habitat generalists are not as restricted by isolated habitats as are habitat specialists and therefore are more likely to have continuous gene flow across unfavarouble habitats. Where adjacent habitats are extremely incongruous, the contrasting habitats will increasingly tend towards an island configuration with more isolation and higher numbers of species, both because of a decrease in habitat generalist species and increased speciation within more fragmented habitat patches.

Rabinowitz rarity and ecological traits

In considering which factors might influence the different components of rarity, the following factors appear paramount.

Geographical distribution is determined primarily by habitat heterogeneity. Habitat-tolerant species will be widespread in habitat-fragmented landscapes, whereas habitat specialists will be restricted in habitat-fragmented landscapes, but widespread when in extensive habitats. The major human impact on geographical distribution of species to date is by habitat fragmentation and destruction.

We predict that there are only a few areas in the world where a correlation between habitat specificity and geographical distribution in plant species exists. These are the regions where large numbers of plant species have persisted safe from the Pleistocene climatic vissititudes which saw other species colonize the changing environments (Diamond & Hamilton 1982, Myers 1988). The large areas of the earth which have been colonized since the Pleistocene by `weedy' species (which we suspect comprises those species with relatively high gene flow rates and therefore low speciation rates) should not show this relationship (*e.g.* United Kingdom (Rabinowitz *et al.* 1986)). Those plant species with low rates of spread, and thus high rates of speciation, are still largely confined to the Pleistocene refugia. It is thus possible to preserve 27 per cent of the higher plant species in just 0.2 per cent of the world's area (McNeely *et al.* 1990). If this is correct, then the numbers of plant species today is possibly a fraction of the pre-Pleistocene flora, and currently species-poor clades may contain survivors of clades which might be particularly speciose under prolonged, stable climatic conditions. Attempts at weighting species based on the numbers of extant species per clade (Vane-Wright *et al.* 1991) are therefore fraught with difficulties.

We are unable to shed much light on factors affecting habitat specificity and population density *per se*: relevant data for understanding these factors do not exist for the CFR, although they are perhaps best known in the Proteaceae. Habitat specificity and population density are presumably determined by a species' genetic makeup, pathogens, predators and competitors, which may act on seeds, seedlings or adult plants. In addition, habitat specificity is determined by the variety and disparity between habitats in an area, both climatically and edaphically. Mans' influences upon habitat specificity and density of plants is *via* introduced pathogens, herbivores, and competitors, and climatic changes. It is particularly difficult to define mans' influences as these can be achieved *via* changes in water regimes, regeneration niche *via* fires (frequency and timing), soil nutrient status and by changes in herbivore communities *via* the effects of pesticides.

Although the Rabinowitz approach to rarity has provided a framework for understanding rarity in

the CFR, there are insufficient data to understand the factors influencing rarity in the region. A major discrepancy between Red Data Book rarity status and the Rabinowitz categories of localized and habitat-specific taxa requires further investigation if Red Data Book status is to maintain scientific credulity.

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Part 3. Ideals and Priorities

3.1.

Protection of Fynbos vegetation: ideal and real-world options

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Protection of Fynbos Vegetation: Ideal and Real-World Options

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ABSTRACT

Schemes are set out for the location of noda of nature reserves aimed at protecting the floral diversity of Fynbos vegetation in the Cape Floristic Region, in South Africa, using distributional data on the Proteaceae. Species richness is significantly correlated between the Proteaceae and other major families and genera of plants representative of Fynbos, for which data are available. In our ideal scheme, 95% of all vascular plant species could be accommodated in 16% of the area occupied by Fynbos vegetation. However, several of our ideal-world noda are not viable options for Fynbos protection. Hence, we identify additional nodal areas that could be proclaimed as nuclei for nature reserves and incorporated into a real-world option for maximizing the protection of Fynbos floral diversity.

INTRODUCTION

The Cape Floristic Region (CFR) occupies 90 000 km^2 in the southern African Mediterranean climate zone (Bond & Goldblatt, 1984). The CFR has the highest recorded ratio of vascular plant species (8 590) to area for any temperate or subtropical region (Bond & Goldblatt, 1984). This relatively high species richness is mainly due to the occurrence of five, largely unrelated, vegetation types (Afromontane Forest, Strandveld, Renosterveld, Fynbos and Karoo), within the CFR, coupled with exceptionally high both *beta*- and *gamma*-diversity in one of these vegetation types: Fynbos (Bond, 1983; Cowling *et al.*, 1989).

In spite of its relatively small area, the CFR is a coherent phytogeographical unit: 68% of species, 19.5% of genera and six families are endemic to the region, with an additional plant family (Bruniaceae) almost endemic. Thus, some 35% of southern Africa's vascular flora occurs within 4% of the subcontinent (Bond & Goldblatt, 1984). In addition, seven large (>250 species) plant families (Restionaceae, Rutaceae, Proteaceae, Ericaceae, Iridaceae, Scrophulariaceae and Campanulaceae) have more than 50% of their southern African species confined to the CFR (Gibbs Russell, 1985).

The CFR has been, and is being, extensively transformed by pastoral, agricultural and urban development (Cowling, 1984; Jarman, 1986), and alien plant invasion (Hall, 1978; Macdonald *et al.*, 1985). This alteration is most evident in Renosterveld and Coastal Fynbos vegetation, and least in Mountain Fynbos (Moll & Bossi, 1984; Jarman, 1986).

To date, there have been three partial reviews dealing with the conservation status of the CFR (Edwards, 1974; Scheepers, 1983; Jarman, 1986), three prescriptions for conservation strategies (Wicht, 1945; Kruger, 1977; Jarman, 1986) in parts, or the whole, of the CFR, and two editions of lists of the region's many threatened and endangered plant species (Hall, *et al.*, 1980; Hall & Veldhuis, 1985). Although more than 56% of southern Africa's Red-Data-Book plant species occur in the CFR (Hall & Velhuis, 1985, little is known about the abundance of these species, or even the numbers of plant and animal species, which

occur within the region's statutory, protected areas (Siegfried, 1989).

Our paper summarizes new information on the dispersion of members of the Proteaceae within and outside statutory protected areas in Fynbos vegetation, and describes options for maximizing the protection of the largely unique flora of this exceptionally species-rich vegetation type. There obviously are pitfalls and biases in basing our approach on one, albeit dominant, family of plants. However, the approach is more than justified by a paucity of information on the taxonomy and distribution of other large families, and an urgent need for a strategy for maximizing the protection of Fynbos floral diversity in the CFR (Siegfried, 1989).

FYNBOS

Although Fynbos is commonly separated into mountain and lowland types, these two vegetation divisions overlap widely in their physical structure and species' assemblages (Cowling *et al.*, 1988). Hence, hereinafter, we treat them as one phytogeographical zonation.

Fynbos is characterized by the presence of representatives of the Restionaceae, usually with a high cover of Proteaceae and Ericaceae, which tend to be the dominant elements in the vegetation (Campbell, 1985). Fynbos manifests itself as either a heathland or a shrubland (Moll *et al.*, 1984). Fynbos occurs on oligotrophic sandy soils where annual precipitation ranges between 250 and 700 mm. Under higher rainfall regimes, however, it may also occur on mesotrophic soils (Campbell, 1985). Fynbos is maintained by fire, with most species apparently adapted to a fire interval of between 10 and 30 years (van Wilgen, 1987).

Fynbos and other vegetation types in the CFR probably expanded and contracted their ranges in the past, depending on changes in temperature and rainfall: Fynbos expanding under drier and warmer fire-prone conditions, Afromontane Forest under moister and cooler climates, Karoo under conditions too dry to sustain regular fires, and grassland under a summer-rainfall regime (Bond & Goldblatt, 1984; Avery, in press). The present distribution of Fynbos is shown in Figure 3.1.1.

Despite the existence of a catalogue of plant species occurring in the CFR as a whole (Bond & Goldblatt, 1984), there are no published statistics for the overall species richness of Fynbos vegetation alone. Indeed, according to Bond & Goldblatt (1984: 6), there is "no reason to try and exclude the relatively small number of species" from other vegetation types from the CFR which they consider to be synonymous with Fynbos. However, we estimate that about 70% of the CFR's vascular plant species occur in Fynbos. Similarly, of the *ca* 1 400 Red-Data-Book plant species which occur in the CFR (Hall & Veldhuis, 1985) 65% are estimated to be Fynbos species.

Fynbos plant-species richness is highest in the southwestern Cape, decreasing along the mountain ranges extending northwards and eastwards (Fig. 3.1.2), reflecting the distribution patterns of all of the CFR's major plant families and some of its characteristic genera (Oliver *et al.*, 1983). Since we have relatively detailed information on the Proteaceae (see below), we correlated species richness per quarter-degree grid square between our data and those for the other major families and genera as reported by Oliver *et al.* (1983). Species richness was significantly correlated ($P < 0.001$, df = 218) between the Proteaceae and all the other families and genera: Ericaceae $r = 0.91$; Bruniaceae $r = 0.87$; Restionaceae $r = 0.85$; Rutaceae: Diosmae (excluding *Agathosma*) $r = 0.82$; Penaeaceae $r = 0.68$); *Aspalathus* $r = 0.87$; and, *Muraltia* $r = 0.82$. This suggests that similar factors influenced speciation and dispersion in the major plant families of the Fynbos vegetation. Consequently, we used the dispersion of the Proteaceae as the basis for our analysis of the phytogeography of the Fynbos flora and its possible state of protection.

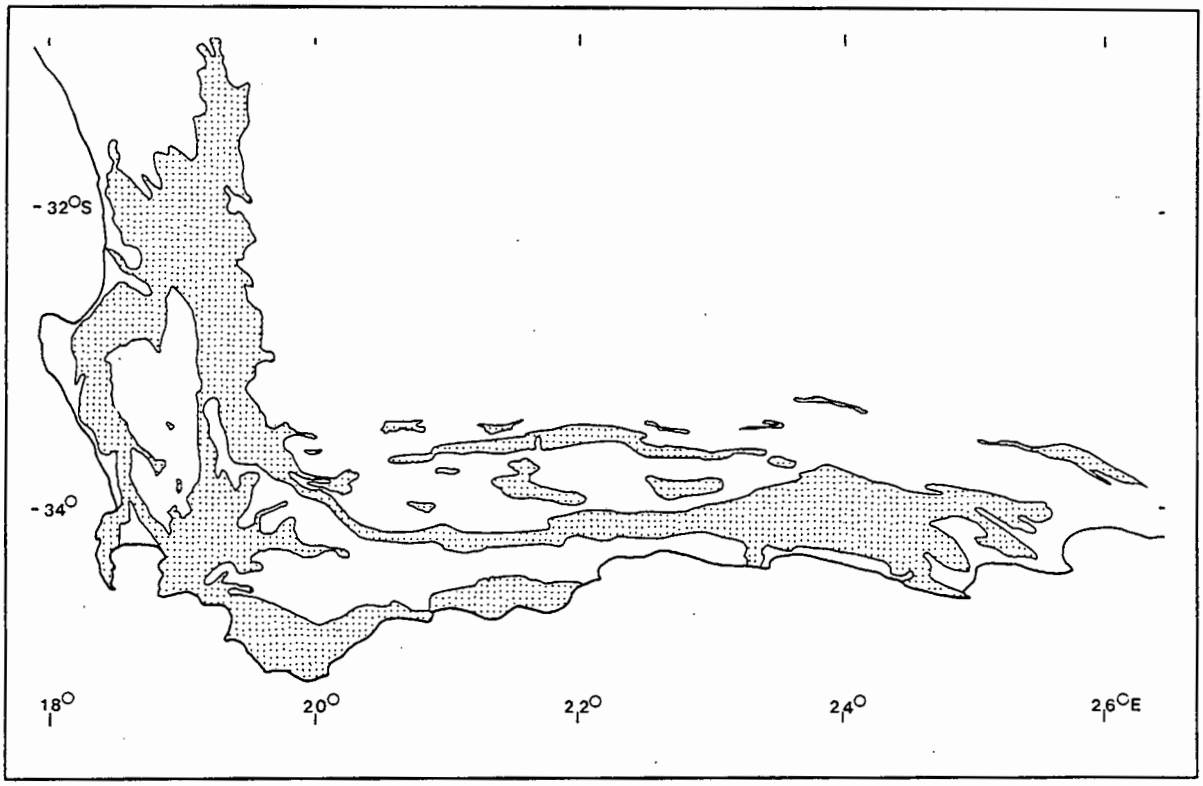

Fig. 3.1.1. The present distribution of Fynbos vegetation (stippled areas) in the Cape Floristic Region.

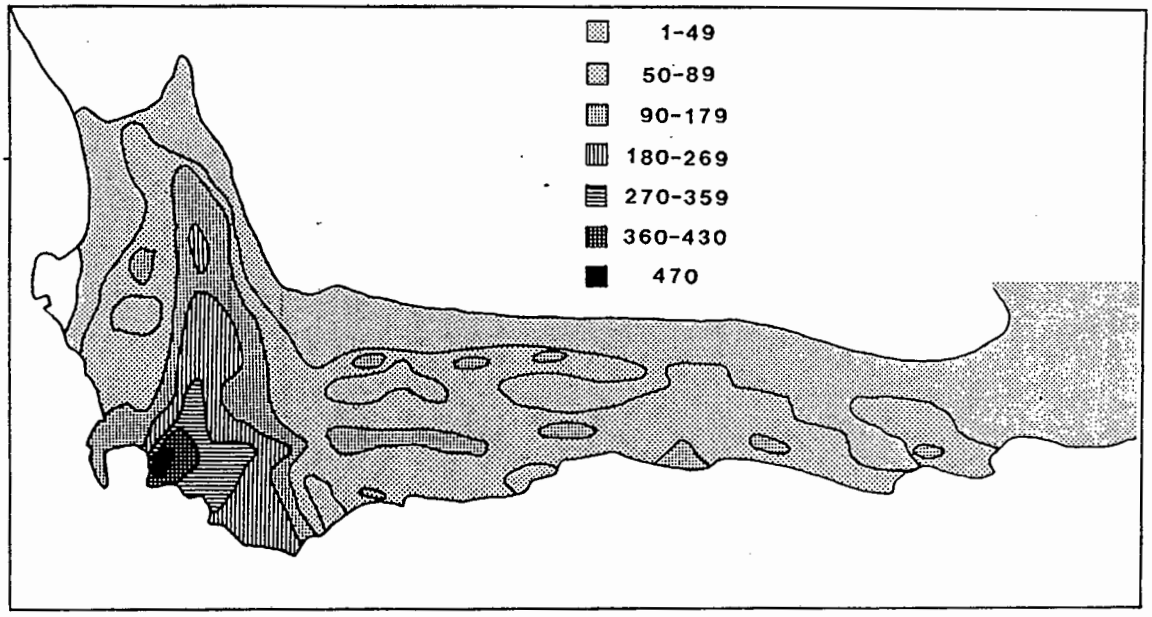

Fig. 3.1.2. The distribution of species richness of vascular plants in the Cape Floristic Region, based on Oliver *et al.* (1983). Isoflors are for all species in characteristic and endemic plant families of Fynbos vegetation (i.e. Proteaceae, Ericaceae, Restionaceae, Peneaceae, Bruniaceae, Rutaceae (excluding *Agathosma*), Roridulaceae, Geissolomaceae, Grubiaceae and Retziaceae, and *Aspalathus* (Fabaceae: 201 spp) and *Muraltia* (Polygalaceae: 116 spp).

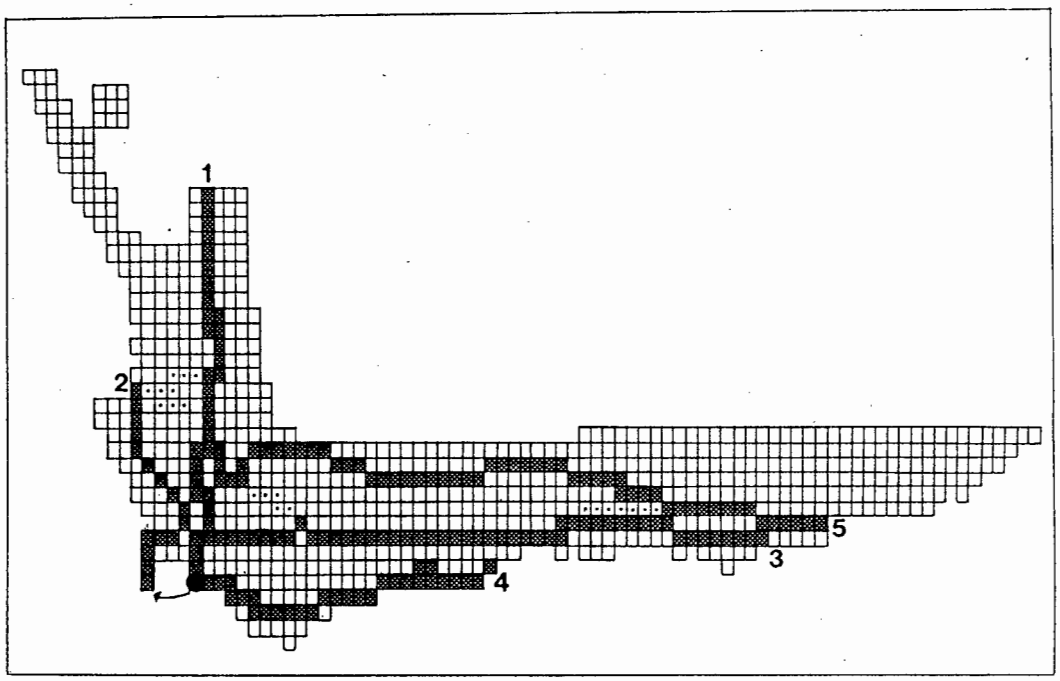

Fig. 3.1.3. The 12 X 13 km grid used for the mapping of the distribution of members of the Proteacea. The numerals identify five transects (stippled) running through areas of high species richness. Transect 2 (west coast) started at the same grid square (large dot) as transects 1 (western mountains) and 4 (south coast). Transects 3 (southern mountains) and 5 (northern mountains) started at primary squares along transect 1. The small dots indicate auxiliary transects used to optimalize grid squares chosen as noda for nature reserves.

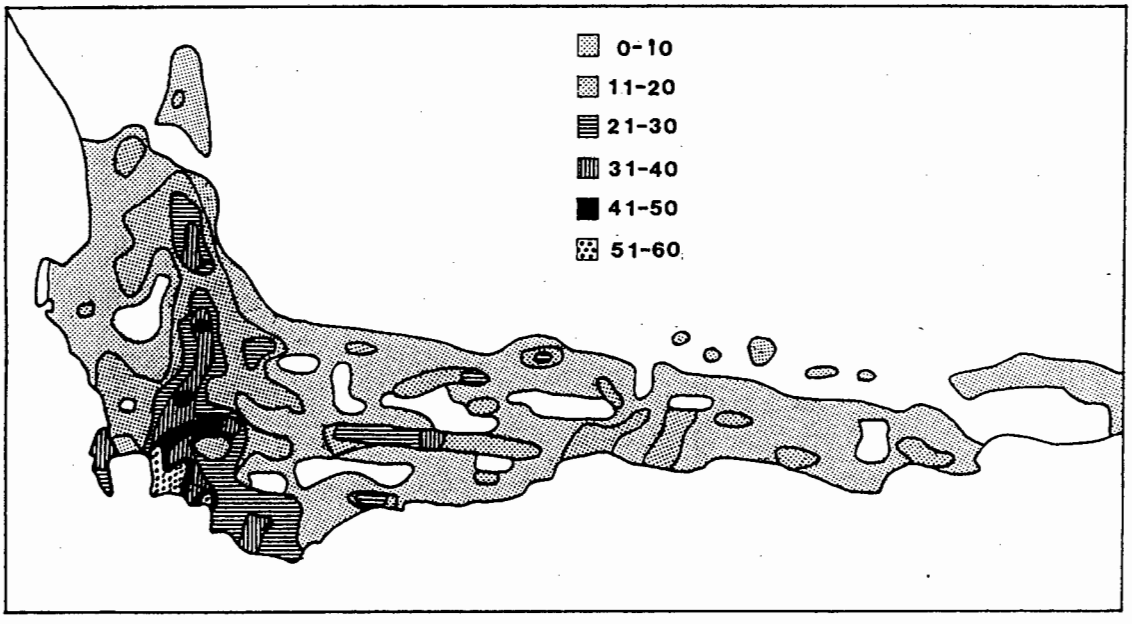

Fig. 3.1.4. Species richness of the Proteaceae in the Cape Floristic Region, according to the eighth-degree grid-square system used in this study.

PROTEACEAE

The Proteaceae family is represented in southern Africa by 366 species of which 320 occur in the CFR (Gibbs Russell, 1985). Almost all the species are confined to Fynbos. Only three new species have been discovered in the CFR in the last decade, suggesting that the total number of species known at present is virtually comprehensive. Moreover, the taxonomy of the family has largely been completed, and the limits of the geographical ranges of most of the species are known as well. On the other hand, many parts of the CFR have not yet been adequately surveyed and many Proteaceae species are poorly represented in herbaria (Gibbs Russell *et al.*, 1984).

MAPPING SPECIES RICHNESS

We used an eighth-degree grid (= 12 X 13 km, Fig. 3.1.3) in mapping the species richness of the Proteaceae in the area covered by Fynbos vegetation, based on all existing distributional records for 326 taxa (species and distinct subspecies). This is a finer scale than that adopted by botanists generally in southern Africa (Gibbs Russell, 1985). The latter, however, does not provide a spatial resolution fine enough for accommodating the actual small-scale levels of physiographic and species' heterogeneity that prevail in the CFR, or the region's many small nature reserves (Siegfried, 1989). These data are available from the authors on request, and are on file permanently at the FitzPatrick Institute. [Appendix 3.]

Starting with the grid square with the highest number of endemic species, termed the 'primary core square', the number of species shared with this core along transects through areas of high species richness (Fig. 3.1.4) was determined. Where species were present in squares adjacent to any one square along the transect, but absent from that square, the species were considered as present. Such 'apparent' species were only accepted when the species was present on both sides of the square to a maximum distance of four grid units (*ca* 45 km). Where, on the transect, the number of species shared with the core square dropped to 50%, a new core square was assigned, provided that at least 25% additional species were present in the square. This procedure was then repeated farther along the transect. The configuration conserving the most (real and apparent) species was chosen in the case of ambiguities.

A list of species present (excluding apparent species) in each of the assigned core squares was then compiled, and the distribution of species not present in core squares was plotted. The grid square with the most species not present in the core squares was designated as a 'secondary core square'. Its species were removed from the map, and the procedure was repeated. Where ties occurred, grid squares with the highest species richness were selected; where species richness was equal, the square containing the most Fynbos vegetation was chosen.

IDEAL-WORLD OPTION

In a theoretical ideal world, 95% of all vascular floral richness could be protected in 16% of the Fynbos area in the configuration shown by Fig. 3.1.5. These estimates involve the following assumptions: the distribution of the Proteaceae species adequately reflects the distribution of the Fynbos flora; the recorded distribution of a Proteaceae species is an accurate reflection of its presence in a particular grid square; the smallest unit of protection equals one square; and, all species recorded in such squares can be effectively protected.

Fifteen primary noda (each 12 X 13 km), as nuclei for nature reserves, could accommodate 69% of the flora in 6% of the area of Fynbos, and 25 secondary noda covering an additional 10% of the area could contain a further 26% of the flora (Fig. 3.1.6). The balance (5%) of species could be contained in an additional 8% of the area. A maximum of 17% of the Cape Flora could theoretically be protected in a single 14 400 ha (12 X 13 km) nature reserve (0.3% of

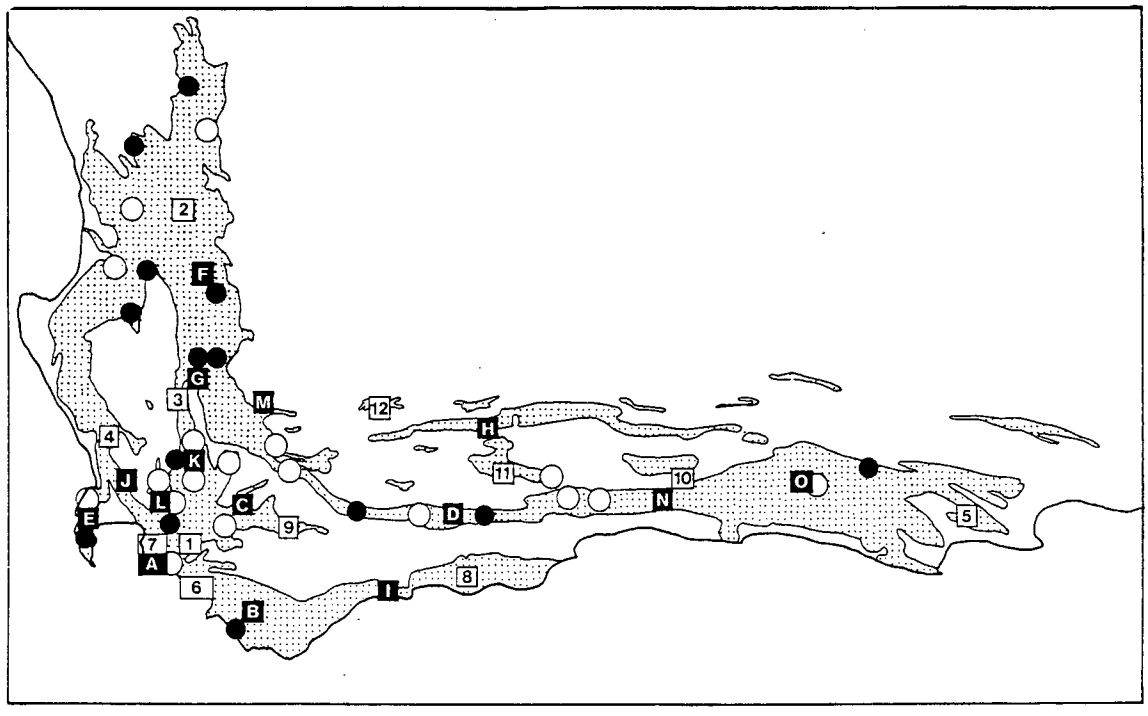

Fig. 3.1.5. The spatial configuration of nodal areas for maximizing the protection of plant species diversity in the Fynbos vegetation of the Cape Floristic Region. Primary noda are identified by shaded squares with letters given in alphabetical order, based on their numbers of unique (peculiar) species. Secondary noda are in clear squares numbered sequentially, based on their numbers of additional species. Two- and one-species secondary noda are indicated by dots and circles, respectively.

the original area of Fynbos vegetation) situated in the Kogelberg State Forest and adjacent coastal area (node A; Fig. 3.1.5). This is roughly consistent with a total species-area relationship of $S = 483A^{0.25}$ (A in km^2; Kruger, 1977) and an independent estimate of 16% (1 407 species out of 8 590) of the total Fynbos flora occurring in the 24 000 ha Kogelberg State Forest (Boucher, 1977).

Our hypothetical ideal-world pattern of protected areas resembles a zoning proposal made by Kruger (1977). His zones were based on Weimark's (1941) phytogeographical centres and the subdivision of Fynbos vegetation into mountain, lowland and arid types. Although Kruger's (1977) proposals did not include recommendations for the actual siting of nature reserves, his zones were a marked improvement on Wicht's (1945) earlier advice for the preservation of Fynbos. A reappraisal of Weimark's (1941) phytogeographical centres of endemism in the CFR (Fig. 3.1.7), based on clustering and ordination of the Proteaceae data set, shows that all the centres of Fynbos endemism could be protected to varying degrees in our scheme. Therefore the allocation of reserves simply on the basis of phytogeographical centres is heuristically sound, although it de-emphasizes the conservation priority of siting reserves in the relatively more species-rich centres.

Our ideal-world scheme is, unfortunately, not practicable in that several of our proposed nodal protected areas no longer are viable options for the protection of Fynbos. For example, primary noda E, J and L and secondary node 4 (Fig. 3.1.5) have been, and are being, transformed rapidly by either urbanization or alien-plant invasion or both.

Nor does our scheme incorporate such other considerations as whether a 14 400 ha reserve could adequately preserve ecological processes

and minimum populations of top carnivores, or whether single-species reserves need to be sufficiently large to maintain overall ecosystem processes. Moreover, our scheme does not consider the seasonal maintenance of pollinator and seed-disperser populations, such as those which migrate within Fynbos vegetation or require non-Fynbos vegetation to complete their life cycles.

REAL-WORLD OPTION

No overall strategy exists for protecting the Fynbos of the CFR. In order to recommend conservation priorities in the CFR based on the distribution of Proteaceae taxa which are currently not in protected areas, we removed all 265 species recorded in the 66 grid squares which had statutory nature reserves encompassing more than 8 000 ha (i.e. greater than 55% of the total area of a 12 x 13 km grid square). The list of nature reserves compiled by Siegfried (1989) was used in this exercise; privately owned mountain-catchment areas being excluded. From the remaining grid squares, species lists were compiled and noda selected on the basis of highest species richness. Four of these nodal grid squares (noda A, B, E and C, respectively, in Fig. 3.1.8) could protect 40% of the taxa, notably in the Elim area of the Bredasdorp phytogeographical district, the Atlantis and Hopefield areas of the Malmesbury district, and the Albertinia area of the Mossel Bay district.

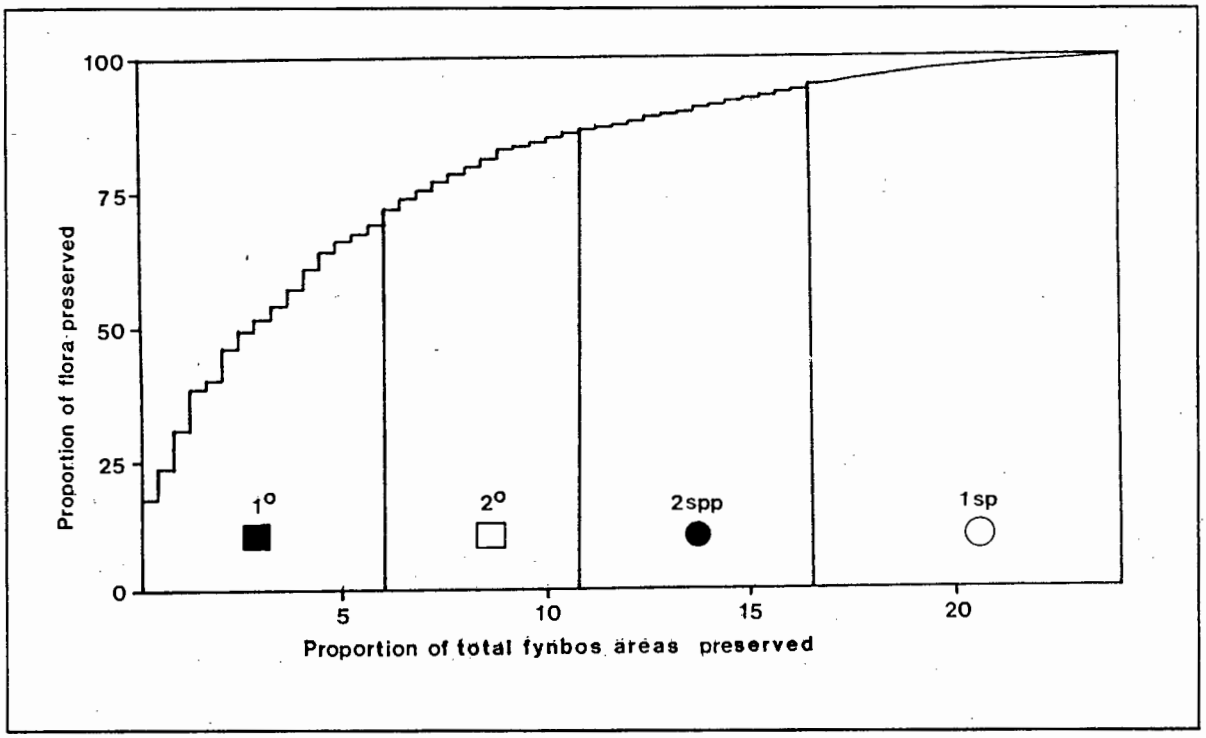

Fig. 3.1.6. The relationship between the protected area of Fynbos vegetation (assuming that all grid squares contain Fynbos exclusively and are totally protected) and the number of protected Proteaceae species, assuming the configuration of noda shown in Fig. 3.1.5.

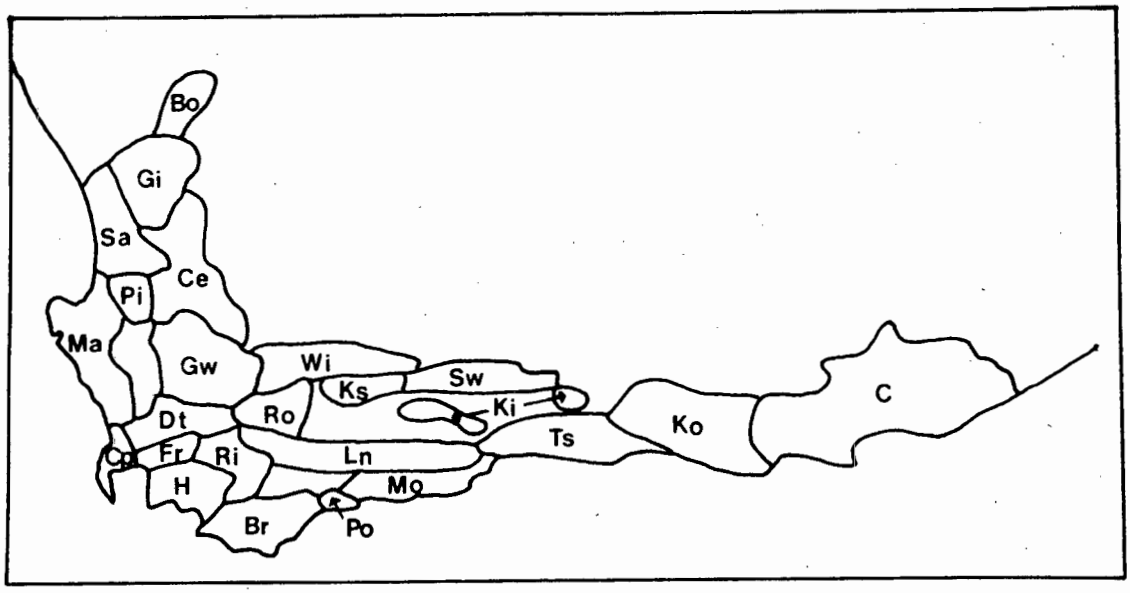

Fig. 3.1.7. Phytogeographical centres of endemism of the Proteaceae in the Cape Floristic Region. See Table 3.1.1 for explanation of letters.

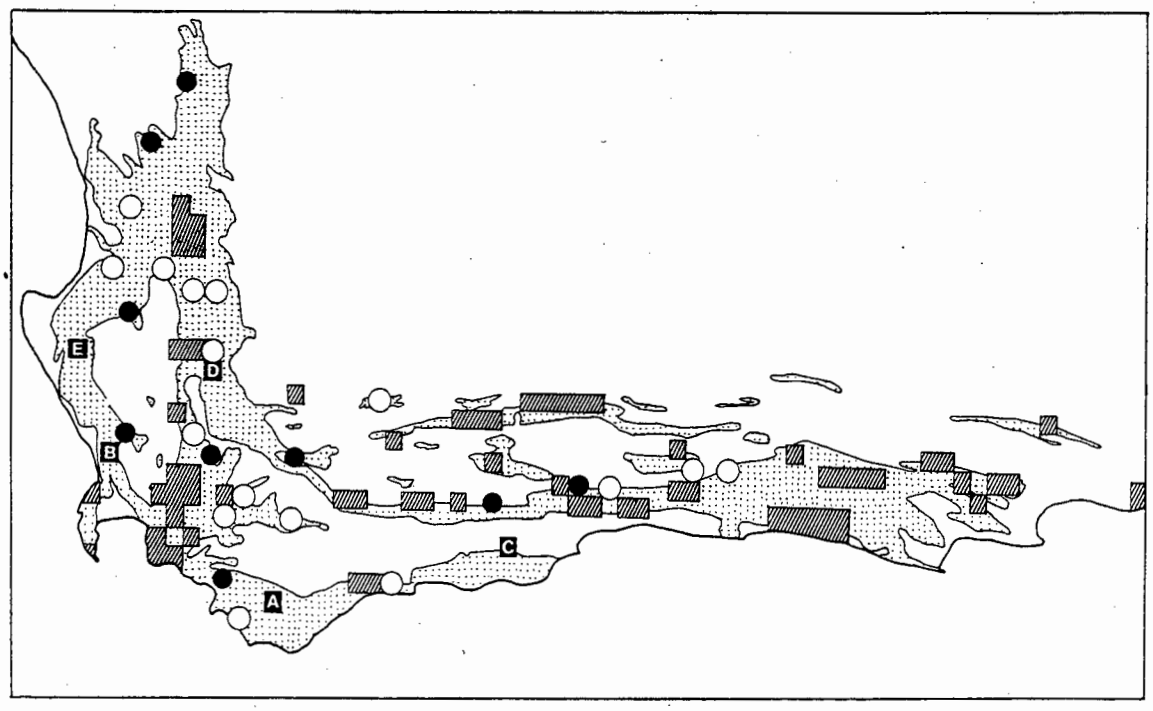

Fig. 3.1.8. The distribution of existing nature reserves and proposed nodal areas for maximizing the protection of plant species in the Fynbos vegetation of the Cape Floristic Region. Hatched areas show grid squares containing existing nature reserves (including state forests) greater than 8 000 ha in extent. Primary noda are identified by shaded squares with letters given in alphabetical order, based on their numbers of unique (peculiar) species. Two- and one-species secondary noda are indicated by dots and circles, respectively.

TABLE 3.1.1.
Existing protected areas and proposed new areas according to Jarman (1986), for the protection of Fynbos vegetation in the Cape Floristic Region.

		Total area of Fynbos (ha) [1]	Proportion protected (%) [2]	Additional proportion proposed for protection (%) [3]	No. nature reserves Existing [2]	No. nature reserves Proposed [3]
Northwestern Province						
Cedarberg District	Ce	256 900	86	0	3	0
Great Winterhoek District	GW	220 600	73	1	7	1
Picketberg District	Pi	49 360	0	47	0	2
Sandveld District						
Sandveld Zone	Sa	230 600	0	12	0	2
Bokkeveld Zone	Bo	85 000	6	0	1	0
Gifberg Zone	Gi	237 000	0	0	0	0
Southwestern Province						
Malmesbury District	Ma	97 200	4	59	13	17
Peninsula District	CP	27 800	100	0	10	0
Riviersonderend District	Ri	91 200	80	0	4	0
Franshoek District	Fr	59 600	98	2	7	1
DuToitskloof District	Dt	136 900	89	12	8	11
Houwhoek District	H	99 100	65	42	14	6
Bredasdorp District	Br	231 700	8	30	16	7
Potberg District	Po	13 000	19	4	1	1
Mosselbay District	Mo	154 900	2	0.4	5	1
Coastal Mountain Province						
Koo Langeberg District	Ro	72 200	83	0	4	0
Langeberg District	Ln	185 300	46	6	5	4
Outeniqua District	Ts	161 900	96	12	33	8
Kouga District	Ko	665 800	27	6	18	6
Southeastern Province						
Cockscomb District	C	260 100	58	40	23	8
Inland Mountain Province						
Swartberg District						
Swartberg Zone	Sw	121 600	100	0	3	0
KleinSwartberg Zone	Ks	57 400	99	0	5	0
Karoo Island Zone	Ki	168 500	33	0	4	0
Witteberg District	Wi	16 100	0	0	0	0
TOTALS		3 699 760			184	75
Proportion of original area of Fynbos			35%	9%		

[1] Calculated from Moll & Bossi (1984).
[2] Data from Siegfried (1989). (Includes afforested areas and some Afromontane Forest.)
[3] Data from Jarman (1986). (Includes areas within legally proclaimed mountain catchments. Hence, proposed and existing protected areas may exceed 100% in total.)

Currently, it is the South African government's policy to devolve authority for the management of state land in the mountains of the CFR to provincial nature-conservation agencies and privatized forestry companies. Consequently, the future of certain mountainous areas, especially in the Outeniqua and Kouga phytogeographical districts, is uncertain. Three other mountainous areas merit special consideration. These are in the Picketberg, Sandveld and Witteberg phytogeographical districts (Fig. 3.1.7). Whereas the Picketberg mountains have been recognized as constituting an important area requiring protection (Jarman, 1986), the latter two areas have been neglected. Nevertheless, the existing network of nature reserves, including state forests, should protect 93% of the species (based on Proteaceae taxa) of the Fynbos flora in the CFR's mountainous districts.

It is therefore in the lowlands of the CFR that protection of the Fynbos flora should be urgently addressed. The urgency is exemplified by the complete transformation, by urbanization, in two years of 5 500 ha of lowland Fynbos vegetation, proposed as a 'False Bay Coastal Park' as recently as 1986 (Jarman 1986). The Sandveld, Malmesbury, Bredasdorp and Mosselbay phytogeographical districts (Fig. 3.1.7) all have less than 10% of their lowland Fynbos vegetation protected (Table 3.1.1), and contain the smallest nature reserves in the CFR. The Bredasdorp district is singled out here as an example meriting special attention. Of the eight Proteaceae species that are endemic to the district, all occur to the west of the Heuningrug mountain. Less than 27% of the area reserved for nature conservation and less than 50% of the area proposed for conservation in the district lie in the area of high Proteaceae endemism. If this pattern is similar for other Fynbos taxa, then, the 47 000 ha of the existing De Hoop Nature Reserve (55% of the total area proclaimed for nature reserves in the district) occurs in the most species-depauperate part of the district, and protects a negligible number of endemic species. The De Hoop Nature Reserve might be a prime candidate for Siegfried's (1989) proposal for the deproclamation of certain nature reserves and the exchange of their land for new reserves.

LONG-TERM PROSPECTS

Any strategy for long-term protection of biotic diversity should encompass evolutionary and biogeographical considerations. These are strongly influenced by climatic change. Currently, several scenarios are being developed for southern Africa in relation to rapid climate change as part of the 'greenhouse' phenomenon. One such scenario speculates that the region of the CFR could become warmer and drier. Moreover, since the cyclone belt could move southwards, the entire region should receive rain in summer, rather than in winter as is the case at present.

Many typical Fynbos species are sensitive to season of rainfall. Under summer rainfall, grasses invade oligotrophic soils and displace the Restionaceae species. These Restionaceae species can be considered as slow-maturing, perennial herbs (Steiner, 1988), so that their replacement by faster-growing grasses would allow near-annual fires, instead of the much longer fire intervals under winter-rainfall conditions. Fynbos can readily be converted into grassland in the eastern Cape Province by repeated burning (Gibbs Russell & Robinson, 1981). The implications of this are that Fynbos taxa will be replaced by grassland taxa if the greenhouse phenomenon is fully realized.

Components of fynbos probably have been replaced by grassland, and *vice versa*, several times during the last two million years (Avery, in press). This would have involved the westward dispersal of many Fynbos taxa along the Langeberg-Outeniqua and Swartberg mountain ranges to high-altitude refugia under conditions of predominantly summer rainfall. This might explain the higher species richness of Fynbos plant taxa in the mountains of the western part of the region, assuming that the

CFR was never subject to a summer-rainfall regime over its entire area. However, there are three major differences between the prehistoric and the envisaged greenhouse climate changes: the future rate of change is projected to be much faster than in the past, and many plant species may not be able to adapt to new environmental pressures or to disperse to potential refugia; the biota of the CFR is not completely protected, and past dispersal routes for species along changing environmental gradients may thus not exist; and, the rapid changes in temperature on the land could be more-or-less uncoupled from those in the sea, so that coastal climate changes may be unlike those of the past.

However, all the major centres of plant endemism in the montane areas of the CFR are protected in nature reserves. These areas probably were refugia for Fynbos taxa during past warmer and drier climates. In the lowlands, however, centres of species richness are more diffuse, and endemic taxa tend not to show concordant distributions. The future protection of Fynbos in the lowlands is thus more problematic.

ACKNOWLEDGEMENTS

We dedicate this paper to Elsie Esterhuysen who collected more than 35 000 botanical specimens during a period of 50 years in the mountains of South Africa. She discovered seven new members of the Proteaceae and innumerable other taxa. Without her collections biogeographical analyses of the Cape Flora would be poorer. We thank I.A.W. Macdonald for comments on the manuscript. The authors' work was funded by the CSIR's Foundation for Research Development, through its Fynbos Biome Project, and the University of Cape Town.

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Part 3. Ideals and Priorities

3.2.

Where should natures reserves be located in the Cape Floristic Region, South Africa?

Models for the spatial configuration of a reserve network aimed at maximizing the protection of floristic diversity.

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Where should Nature Reserves be Located in the Cape Floristic Region, South Africa?
Models for the Spatial Configuration of a Reserve Network Aimed at Maximizing the Protection of Floristic Diversity

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Abstract: *The SLOSS debate can only be resolved by considering the optimal spatial configuration of a nature-reserve system. Only once the target species determined by such considerations have been identified can the size of the constituent reserves be determined. We explored two null models for a spatial configuration of reserves in the Cape Floristic Region, South Africa, based on the distribution of species in the family Proteaceae (Angiospermae: Rosidae). In the first model, reserves (12 X 13 km grid squares) were assigned at random for comparison with existing, proposed and theoretically ideal configurations. In the second model, the theoretically ideal reserve configuration was constructed using the first model as a pre-assigned configuration. Two methods were used to iteratively select a reserve from the grid system: richness of unprotected species (species-richness algorithm); and, the sum of the rarity indexes for each unprotected species (rarity algorithm). Both algorithms yielded configurations requiring fewer reserves than those contained in proposed or existing configurations, although neither algorithm was perfect. The existing reserve configuration performed no better than the random model, assuming that the principal goal is protection of all species. We confirm that the best approach to designing a reserve configuration which maximizes the protection of species richness is to identify areas of high endemism and richness within particular biogeographical regions.*

Running head: Spatial Configuration of Nature Reserves

Introduction

The SLOSS (single large or separate small reserves) debate combines two independent issues: the optimal spatial configuration of reserves in heterogeneous areas; and, the optimal number of reserves accounting for a given area. Whereas the second issue has been dealt with in the literature from the start of the debate, both theoretically (reviewed by Margules et al. 1982; Burgman et al. 1988; Simberloff 1988) and more practically (e.g., incidence function (Diamond 1975; Dawson 1984)), the former has been largely ignored.

The arguments arising from the SLOSS controversy have been mainly over such phenomena as the loss of heterosis or gene flow and increased extinction rates, and other matters inherent in attempts to preserve fragmented remnants of large ecosystems (Soule 1986; Soule & Simberloff 1986). Further confusion has arisen by a focus on the merits of protecting maximum species richness in a single reserve, rather than a configuration of reserves protecting the maximum species richness in the minimum area of the original "mainland" area.

In this context, it is necessary to follow Margules et al. (1982) in separating the goals of protecting "maximum species richness" and "rarity and representativeness". The a priori selection of reserves with the primary goal of protecting species richness has not been well explored in the literature (Terborgh & Winter 1983).

In general, the protection of biotic diversity has been second to the goal of protecting areas of outstanding scenic or recreational values (Terborgh & Winter 1983). Kirkpatrick (1983) first appreciated that every area designated as a reserve should alter the importance of subsequent potential reserves by changing the milieu of the "preserved" species. Attempts to overcome the problem of the changing status of such subsequent reserves using multi-criteria scoring procedures have not been efficient (Pressey & Nicholls 1989a). The selection of discrete areas, using multi-criteria scoring procedures, has been thoroughly reviewed (Margules & Usher 1981; Margules 1986; Usher 1986; and references in Pressey & Nicholls (1989a)).

Few prescriptions or evaluations of reserve systems aimed at maximizing the protection of species richness have been made for geographical areas to date. These studies (Terborgh & Winter 1983; Purdie et al. 1986; Diamond 1986; Myers 1988) have assumed that effective and efficient reserve systems can be based on identifying areas of high species endemism and richness within recognized biogeographical regions. Although intuitively obvious, these principles have not been evaluated to date.

In this report we employ null models for exploring the efficiency and spatial variability of nature-reserve networks in the Cape Floristic Region (CFR) of South Africa (Fig. 3.2.1), in relation to maximizing the protection of the region's floral diversity (= species richness). We studied the distribution of members of the vascular plant family Proteaceae (Angiospermae: Rosidae), the best known family in the region, as representative of overall biotic diversity (Rebelo & Siegfried 1990).

There is a single major concentration of Proteaceae species in the south-west of the CFR (Oliver et al. 1983), with richness decreasing to the north and east. This pattern is identical for all the major vascular plant families (Ericeae, Restionaceae, Rutaceae, Bruniaceae) and genera which characterize the CFR and for total species richness in the region (Rebelo & Siegfried 1990).

The CFR is one of the world's richest centres of biotic diversity (Siegfried 1989; Rebelo & Siegfried 1990). Our proposal for protecting a maximum amount of species richness in the CFR flows from an iterative approach that has been used primarily in Australia (Kirkpatrick & Harwood 1983; Margules et al. 1988; Pressey & Nicholls 1989a,b). The iterative approach has also been applied, in a crude form, to Andean butterflies (Thomas & Mallorie 1985).

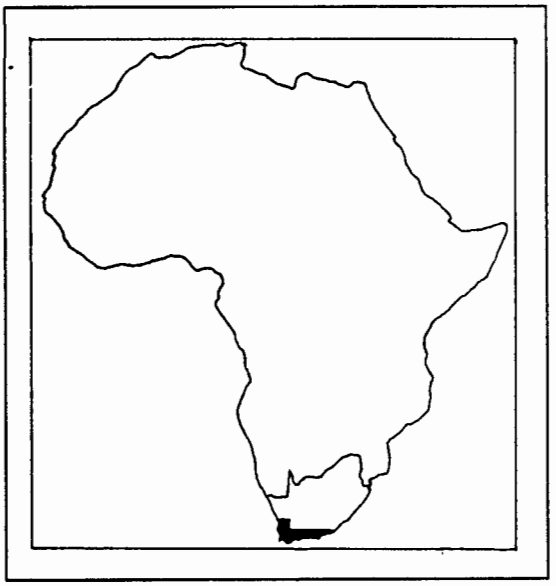

Figure 3.2.1. The location of the Cape Floristic Region (shaded) in Africa.

Methods

All records of the distribution of members of the Proteaceae in the CFR were plotted in accord with a 12 X 13 km grid-square system (Fig. 3.2.2), using data obtained from the literature and herbaria. Further details on the data set are given in Rebelo & Siegfried (1990). Some 332 taxa (species and distinct subspecies: hereinafter referred to as species) occur within the gridded region. One of these species (*Protea simplex*) occurs predominantly outside the region and does not co-occupy any grid square with a CFR species: it was excluded from the analyses. Only three of the remaining taxa are not endemic to the gridded region.

The terms "protected" and "unprotected" are used throughout this report to express the occurrence of species respectively inside and outside the boundaries of one or more grid squares designated, either in theory or in practice, as a nature reserve or a nature-reserve system.

Null Models

The null model for assessing the efficiency of the algorithms employed here consisted of a random selection of geographical grid squares (Rapoport et al. 1986). A cut-off of two species was chosen on the assumption that depauperate grid squares would be worthless, unless they contained endemic species or no other suitable land existed for a reserve system. We did not consider these exceptions in assigning the null model. Additionally, the same grid square was not assigned randomly more than once in any run. Twenty-five iterations were found to be adequate, giving medians, means and ranges similar to 100 iterations.

The null model for evaluating the spatial configuration of a reserve system proceeded from the random grid squares assigned in the preceding model. The optimal reserve configuration was established from this "pre-assigned initial reserve configuration", using, separately, species-richness and rarity algorithms (see below). In each case, the proportion of times each grid square occurred in the 25 iterations was used to determine which grid squares were invariably required in the resultant reserve configuration. These were compared to Sorenson's (1948) coefficient of community (CC):

$$CC = 2S_s / (S_j + S_k)$$

where S_s is the number of species shared by grids j and k, and S_j and S_k are the total species in grids j and k, to assess whether constraining was simply related to the similarity of adjacent grid squares.

A combination of the results of the two models allowed an assessment of the relationship between the number of species occurring in a randomly assigned reserve configuration and the number of additional reserves (grid squares) required to protect all of the species.

Reserve Selection Algorithms

A species-richness algorithm calculated, at each iteration, the number of species not assigned to a "reserve" in each grid square. The richest grid square was selected. Where ties occurred the square with the highest rarity factor (see rarity algorithm below) was selected. Where this did not resolve the tie, a square with the highest initial rarity factor was selected. A grid square was randomly chosen from the tied squares in cases in which ties were not resolved.

A rarity algorithm was calculated for each grid square, at each iteration, as follows:

$$\text{Rarity} = \sum_{i}^{j} (k/a_i)$$

Where j is the number of species in the grid square, a is the number of unreserved grid squares containing species i, and k is the total number of unreserved grid squares. In the analysis, the entire region was used as the sample (k = 857); not merely the 550 squares containing Proteaceae. Thus, initial values for

a_i ranged from 5.0 to 857, rather than 3.2 to 550. Where ties occurred, the square with the most unprotected species was selected: where this did not resolve the tie, the square with the highest initial rarity factor was selected. Remaining ties were randomly resolved.

Both models were used to assess the total number of reserves required to protect all species in at least 1, 2, 3, 4, 5 and 10 grid squares.

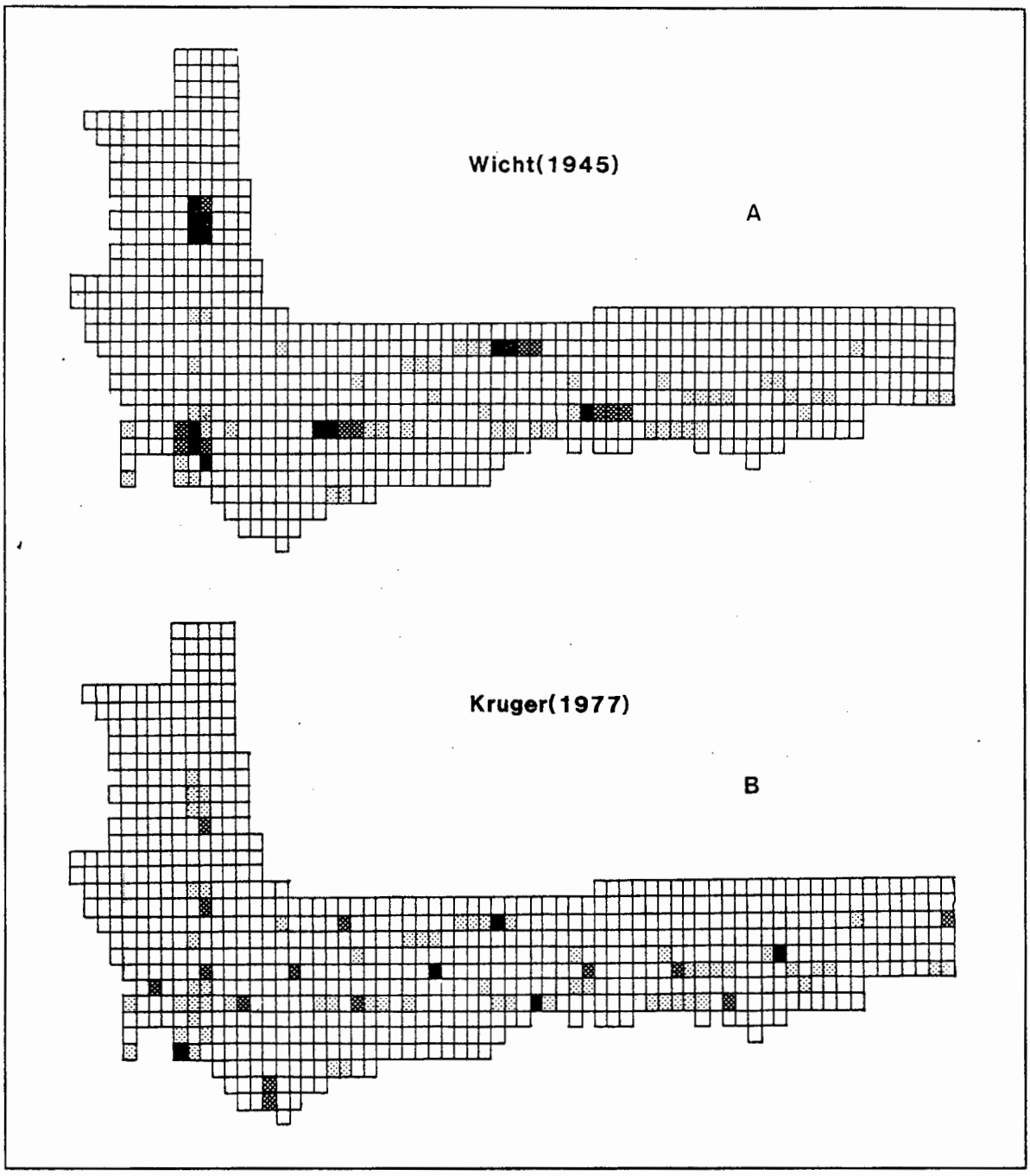

Figure 3.2.2. The 12 X 12 km grid used for mapping the distribution of members of the Proteaceae, showing historical prescriptions for nature reserves (hatched squares) by (A) Wicht (1945) and (B) Kruger (1977), overlaid on the existing reserve network (shaded squares, overlap solid).

Assessing Historical Prescriptions

Three prescriptions for configurations of nature reserves have been made for the CFR as a unit. Wicht (1945) proposed a series of five reserves to protect the flora of the region. To assess the efficiency of Wicht's system, we designated each grid square that overlapped with his reserves as a reserve (Fig. 3.2.2a), and calculated the number of species theoretically protected in such a configuration and the number of additional reserves required to protect all species.

Kruger (1977) proposed that each major CFR vegetation type should be preserved in each of Weimark's (1941) biogeographical zones. His scheme embraced 19 reserves (one per zone), but did not specify where within these zones reserves should be located. We assigned the most species-rich grid square as a reserve in each of the zones (Fig. 3.2.2b), selecting one grid square of 156 km^2 as satisfying Kruger's (1977) arguments for a minimum reserve size of between 100 and 1,000 km^2. We then calculated the number of species theoretically protected in such a configuration and the number of additional reserves required to protect all species.

Rebelo & Siegfried (1990) described an optimal reserve configuration for the CFR by graphically selecting 15 "primary core squares" on a transect system through areas of high species richness for the same Proteaceae data base used herein. "Secondary core squares" then were selected manually on the basis of unprotected species richness, using highest total species richness and indigenous vegetation types as successive criteria for resolving ties.

Finally, we evaluated the currently existing reserve configuration by selecting each grid square in which more than 8,000 ha of indigenous vegetation (i.e., 55% of the area of a grid square) is preserved in statutory nature reserves (Fig. 3.2.2) (Siegfried 1989). Mountain Catchment Areas, which are de facto reserves but for which management procedures may not necessarily benefit plant species in perpetuity, were excluded from the assessment.

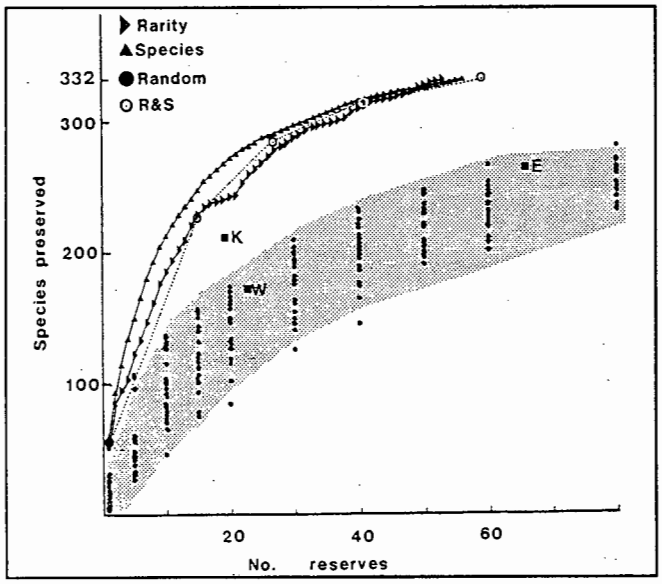

Figure 3.2.3. The relationship between the number of reserves (= grid squares) and the number of protected Proteaceae species (n = 332) using the rarity and species-richness algorithms. The dots show a null model consisting of 25 selections of 1,5, 10, 15, etc., grid squares containing more than two species (n = 409); shaded area is 2 X SD about the mean. K and W represent historical prescriptions for the protection of the flora by Wicht (1945) and Kruger (1977), respectively, the dotted line (RS) shows Rebelo and Siegfried's prescription, and E indicates the position of the existing reserve network.

Results

Efficiency of the Algorithms

Comparison with the Null Model: Protecting Species Once

The performance of the species-richness and rarity algorithms versus the null model are shown in Figure 3.2.3. Whereas the rarity algorithm contained all the species in 53 grid

squares, the rate of inclusion per additional grid square increased faster initially for the species-richness algorithm which required 56 grid squares. Since the rarity algorithm assigns to grid squares containing rarer species a higher value than to relatively species-rich squares containing common species, the cumulative total of species protected yields a stepped curve.

Both Rebelo & Siegfried's (1990) and Kruger's (1977) configurations performed significantly better than the null model

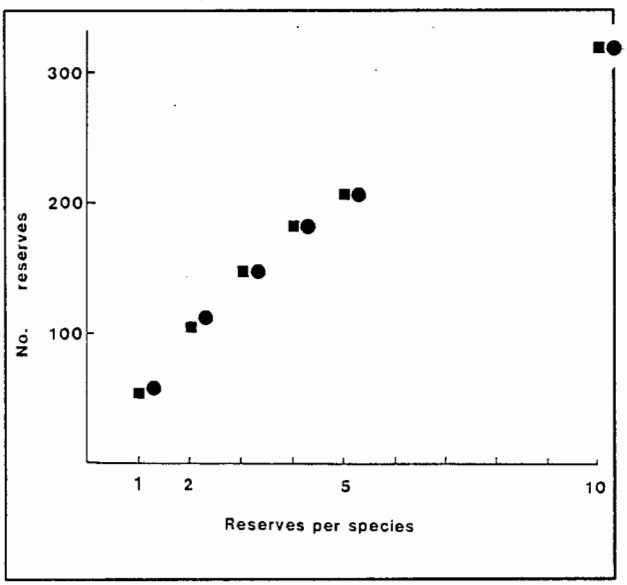

Figure 3.2.4. The number of reserves (= grid squares) required to protect each species of Proteaceae in one or more reserves using the rarity (■) and species-richness (●) algorithms. A total of 550 grid squares contained at least one species.

(Fig. 3.2.3). However, the currently existing reserve configuration and Wicht's (1945) configuration contain no more species than predicted by the null model (Fig. 3.2.3).

Although both the rarity and species-richness algorithm performed far better than a random alternative, and better than any other algorithm (Fig. 3.2.3), they did not yield a possible optimal reserve configuration. For instance, both algorithms yielded a final configuration containing one reserve fewer when the final five reserves selected by the algorithms were pre-assigned as reserves. The sequence of selecting reserves was found to have little influence on the number of reserves required when using the rarity algorithm, but the species-richness algorithm proved susceptible to the preselection of reserves selected near the middle of the sequence. These differences are due to the influence of the secondary and tertiary selection of algorithms when initial scores are tied, which may select suboptimal grid squares as reserves. This effect is more apparent when the species-richness algorithm is used than the rarity algorithm, suggesting that an efficient algorithm will result in fewer changes in the actual reserves allocated if the sequence of reserve selection is initially forced.

The use of total species richness per grid square, rather than unprotected species or rarity factor, to resolve ties did not affect the total number of reserves required to contain all the species.

Protecting Species More than Once

The number of reserves required to preserve each species in more than one reserve increased by just under a factor of two (Fig. 3.2.4). The rate of increase is less than two, since certain species occur in fewer than the required number of grid squares. However, the rate of increase is not simply related to the number of species occurring in fewer grid squares than required, since the spatial distributions of certain species may require more reserves to contain the remaining species. Thus, to protect all the species twice requires three reserves fewer than double that required to contain all species once, even though 13 species only occurred in a single grid square (Table 3.2.1).

Table 3.2.1. The frequency with which Proteaceae species protected by the rarity algorithm in relation to the minimum number of nature reserves required per species.

No of reserves in which species preserved	Minimum number of reserves required per species						
	1	2	3	4	5	10	all occurrences
1	124	13	13	13	13	13	13
2	57	99	27	27	27	27	27
3-5	80	90	134	115	96	60	60
6-10	49	67	63	74	83	92	67
11-20	16	47	64	63	66	65	73
21-50	6	15	27	33	39	59	73
51-100	0	1	4	7	7	15	16
> 101	-	0	0	0	1	1	3

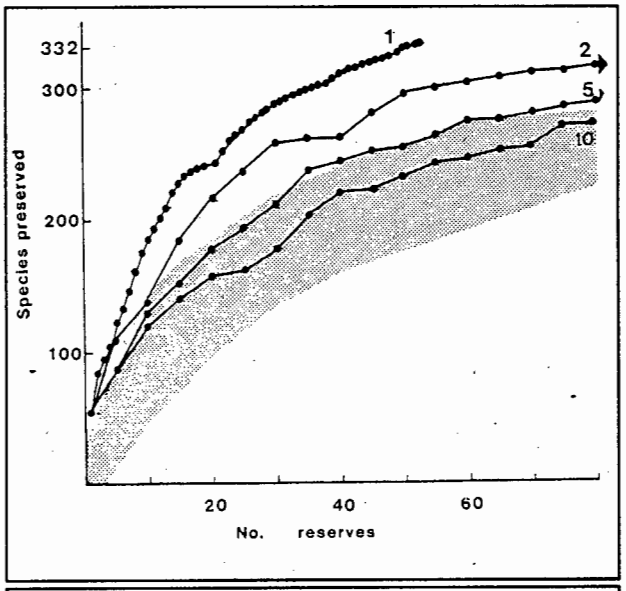

Figure 3.2.5. The relationship between the number of reserves (= grid squares) and the number of protected Proteaceae species using the rarity algorithm to protect all species once (1), twice (2), five times (5) or 10 times (10) relative to a null model of the random selection of grid squares (shaded- see Fig. 3.2.3).

It should be noted that the requirement for each species to be protected in five or 10 reserves resulted in an initial efficiency of protection indistinguishable from that of our null model (Fig. 3.2.5). However, in these cases the existing reserve configuration comprises only 30 and 20 per cent, respectively, of the total number of reserves required to achieve the goals.

The Utility of the Null Model

The number of species preserved is not an adequate measure of the efficiency of a reserve configuration. Although a strong positive correlation exists ($P < 0.001$) between species protected and the number of additional reserves required to protect all species (Fig. 3.2.6), there is a negative correlation ($P < 0.01 - 0.16$) between species protected and the number of additional reserves required to contain all species for any theoretically existing number of reserves. Furthermore, as the number of existing reserves increases, the more accurately one can estimate the number of species protected, but the higher the varience in the number of additional reserves required for optimal protection of all species. Thus, the number of additional reserves required to protect the entire flora in one reserve increases in range from five for five existing reserves to 11 for 80 existing reserves, although the range in the number of species contained in the existing reserves is 79 and 53, respectively. In the latter case, the actual range is far smaller than the

potential of from 80 to 133 (i.e., 0-53 additional reserves are required to protect all the species once). This is because squares containing fewer than two species were excluded from the null model. Relaxing this condition should result in a far greater variance in the number of species protected per set of reserves, with the overall relationship between the variables apparently approaching $y = x^2$; it would also result in a statistically more significant relationship between the number of species protected and the number of additional reserves required for any given reserve network. As a consequence, it is not possible accurately to predict the efficiency of a reserve system from the number of reserves currently in existence, nor from the number of species contained in the reserve system. Perhaps the only accurate prediction is the number of additional reserves (relative to the optimal number for the algorithm) required to contain the desired number of species.

Wicht's (1945) prescription requires 48 and 49 additional reserves for the species-richness and rarity algorithms, respectively; Kruger's (1977) prescription 11 and 13; and the existing reserves system 32 and 32. Wicht's prescription effectively includes only four (17%), Kruger's six (32%), and the existing network 16 (23%) of the 53 key grid squares. To protect all the species in the three cases, using the rarity algorithm, requires totals of 72, 64 and 98 reserves, respectively. Hence, the efficiency (E) of the reserve systems, defined according to Pressey & Nicholls (1989a) as

$$E = 1 - (X/T)$$

where X is the total number of reserves needed to contain all the species and T is the total area (550), is 0.869, 0.884 and 0.822 for Wicht's (1945), Kruger's (1977) and the existing reserve configurations, respectively. The comparable values are 0.904 and 0.898 for the efficiencies of

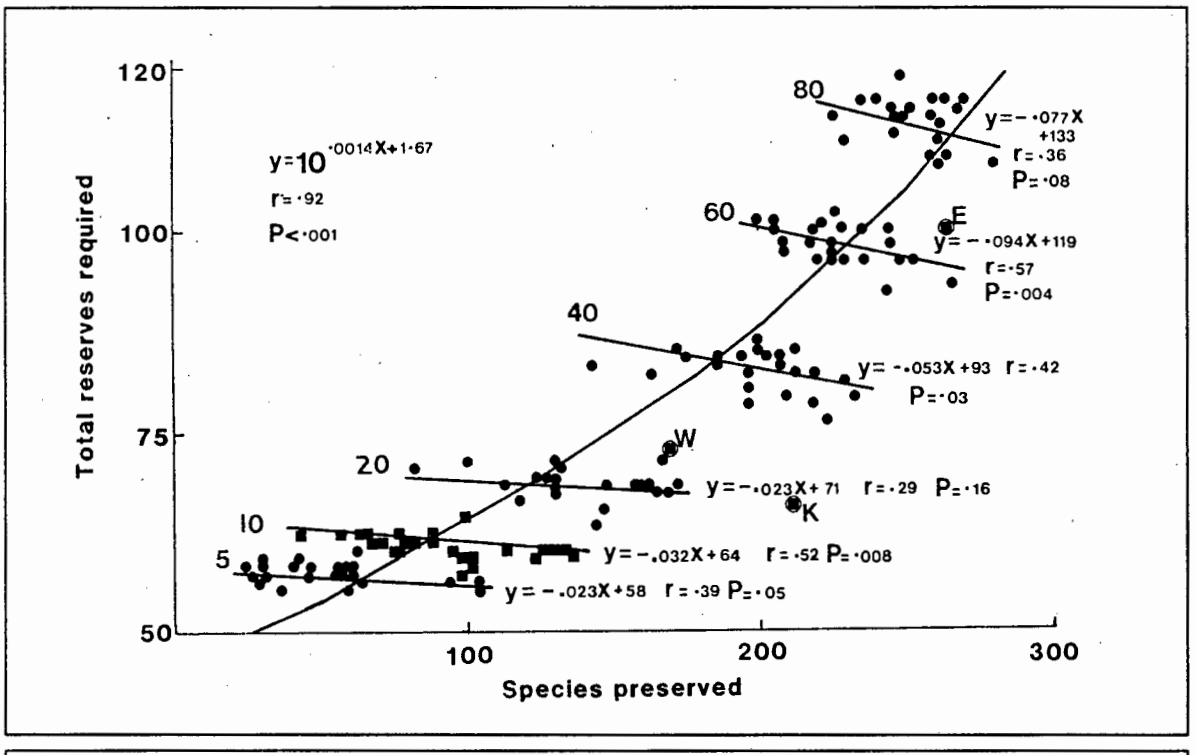

Figure 3.2.6. The relationship between the number of Proteaceae species protected in a randomly allocated network of 5, 10, 20, 40, 60 and 80 reserves (each containing two or more species) and the number of additional reserves required to protect all the species using the rarity algorithm. The equation, its correlation and signifance are given for each reserve network, as well as for the entire data set. K and W represent historical prescriptions for the protection of the flora by Wicht (1945) and Kruger (1977), respectively, and E indicates the position of the existing reserve network.

the rarity and species-richness algorithms, respectively. The high values for the efficiency of the reserve system is a function of the clumped dispersion of the species, which allows a few reserves to protect all the species. Thus values for null models are 0.876 (± 0.003 SD) for 20 existing reserves and 0.822 (± 0.005 SD) for 60 existing reserves (Fig. 3.2.6).

The Spatial Location of Reserves

The reserves (Fig. 3.2.7a) selected initially by the algorithm are those grid squares with high species richness and endemism. Furthermore, more reserves are located in the central-south-west than in the east, reflecting the high "turnover" of species in this region (Fig. 3.2.7a).

Sorenson's (1948) coefficient proved to be worthless in predicting the scatter of reserves around a single location. Those reserves which were invariably selected (30% of the total number of reserves; Fig. 3.2.7b), regardless of the randomly assigned initial reserve configuration, contained localized endemic species. The actual spatial configuration of reserves reflects the relative distribution of localized endemics, and not the relative amount of species richness shared between areas. In cases in which localized endemic species had relatively large distributional ranges (i.e. several grid squares), the reserves were less constrained and occurred equally often in adjacent grid squares; this occurred in about 13% of the reserves. In one case a grid square adjacent to the one selected in the optimal configuration was significantly more often selected in the null model (Fig. 3.2.7b).

The selection procedure, specifically the selection of ties, constrains the location of reserves far more than is actually required to contain each species a given number of times. The secondary selection criterion is required to ensure an efficient reserve configuration, but the location of reserves may be expanded (at the expense of protecting additional populations of more common species) to the overlap in distributional ranges of the species being selected at the specific iteration. Figure 3.2.8a shows those grid squares which could be substituted to provide an equally efficient reserve configuration (for containing all species once). All these squares are those which resulted in ties during primary selection at one or other iteration. It should be noted that reserves with the most variable location are those selected last by the algorithm.

The rarity algorithm achieves its efficiency by selecting rarer species initially, thus preventing the more common species (which are more likely to be protected in subsequent iterations) from biasing the choice of grid squares. However, the algorithm is not perfect and in 13 cases (Fig. 3.2.8b) the subsequent reserves protected some of the species responsible for a grid square's selection. In almost all cases, one of these grid squares was "picked up" by the algorithms following the assignment of random reserves (compare Figs 3.2.7 & 3.2.8). A few grid squares which could not be substituted were not always selected. However, in each of these cases, one of the randomly preselected reserves contained some of the species present in the grid square, so that an additional reserve, not constrained to the optimal square, was required to protect the remaining species.

Thus, there are well over 100 (and possibly several hundred allowing for permutations) different "optimal" reserve configurations which will contain all the Proteaceae species in the CFR in 53 reserves. The configuration displayed in Figure 3.2.7a is the one in a handful that, according to the algorithm, should protect the most populations in 53 reserves.

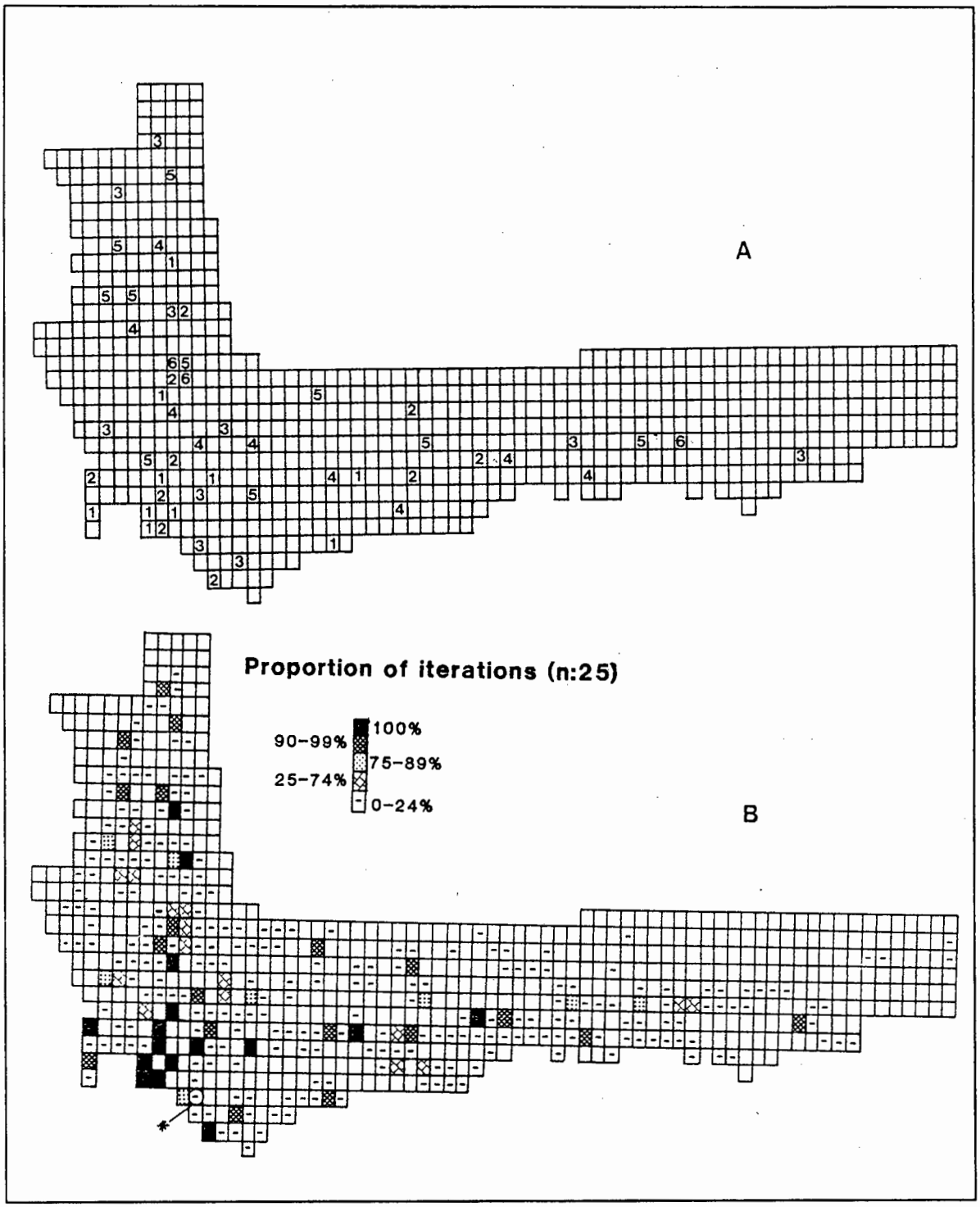

Figure 3.2.7. (A) An optimal reserve configuration for protecting all Proteaceae species using the rarity algorithm; the specific configuration shown is that additionally preserving the maximum number of populations of species; numbers show the sequence (1 = 1-10, 2 = 11-20, etc.) in which reserves were allocated. (B) The proportion of iterations (n = 25) in which grid squares were selected using the rarity algorithm to protect all species, following the random allocation of 20 reserves containing two or more species; the 0-24% category is indistinguishable from the random allocations which are included in the presentation. The asterisk indicates the only grid square selected preferentially to the optimal configuration by the null model.

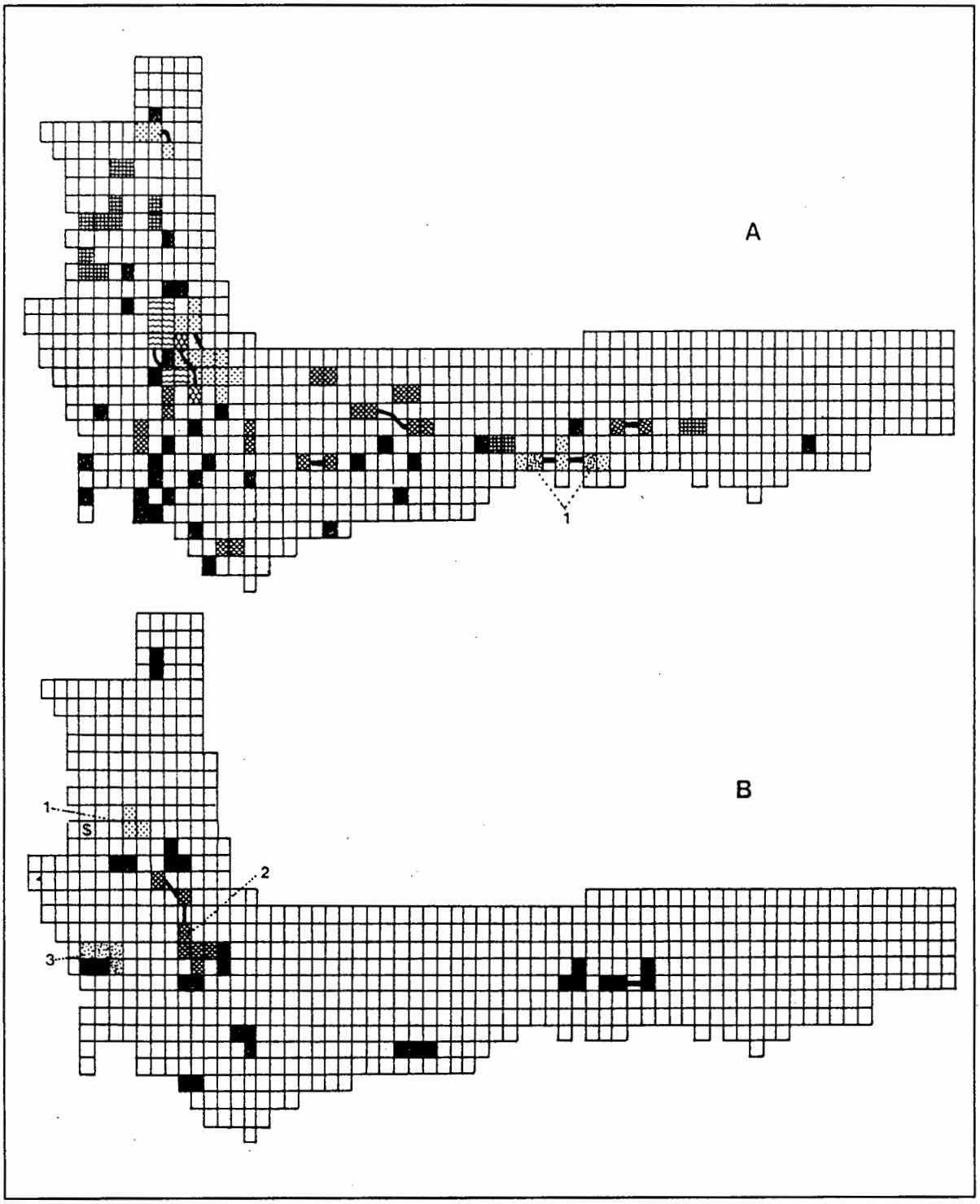

Figure 3.2.8. Spatial constraints on the positioning of reserves required to protect all Proteaceae species using the rarity algorithm, based on: (A) the iterations which resulted in ties in selecting grid squares as reserves (contiguous hatched squares; solid squares show reserves without an option), and (B) the removal of species which influenced reserve location but which were additionally protected in subsequent iterations. Broad lines join disjunct alternatives . It should be noted that in (A) the darkly stippled squares (1) are constrained by a species which occurs predominantly outside the CFR; excluding this species from the data base expands the potential reserve location. In (B) the expansion of the potential reserve location (1) only occurs if there is a reserve at $. Several fairly widespread species have shared disjunct distribution ranges in area (2); it being uncertain as to whether this is due to a fragmented habitat or the data base. Any reserve to the north-west of area (3) relaxes the constraint on the location of the reserve from the solid squares to that of the stippled region.

Discussion

We have not addressed in particular the issue of reserve size in this report, because our results indicate that there is little point in prescribing minimum or optimal reserve sizes before a configuration of reserves has been designated. Only once the importance of the reserve in the regional context has been evaluated can the size of each reserve be determined, based on the specific requirements of those species which require protection. In the real world of rearguard conservation, however, such luxurious approaches seldom can be taken. Hence, we suggest that, without exception, viable populations of any Proteaceae species, and most other CFR plant species, can be protected in an area far smaller than 12 X 13 km, since many species typically occur in populations only a few hectares in extent (Hall & Veldhuis 1985; Tansley 1988). The minimum size of reserves in the CFR will probably be determined by the effects of such ecosystem processes as fire (Bond et al. 1988), since local representatives of high-trophic levels (e.g., vertebrate predators and plant dispersers and pollinators) apparently are able to move between reserves, at least in mountainous areas (Kruger 1977). Furthermore, provided ecosystem processes are maintained, reserves as small as 5 ha may preserve populations of plant species indefinitely (Cowling & Bond in press). There is thus, in effect, considerable flexibility in obtaining suitable reserves within the grid squares designated for preservation.

We have used a "snapshot" approach (where species are presumed to be stable entities, i.e., not subject to extinction in any particular reserve, nor tracking any climatic changes), on the assumption that a 12 X 13 km reserve should contain sufficient local populations to prevent stochastic extinction, and allow limited climate tracking (Bond et al. 1988; Bond 1989). No data on these requirements are available for the CFR (Bond 1989), although the distribution of naturally rare species suggests that they tend to occur in refugium areas (high relief, high altitude areas) (Rebelo & Tansley MS).

We ignored the problem of species assemblages which might be protected in particular, because they are unique. We justify this approach on the basis that the goal of our reserve system is to protect species richness, and that unique species assemblages are not identifiable at the geographical scale of our approach. Furthermore, such assemblages might be the chance result of previous climatic change and, thus, have no relevance to the preservation of the constituent species within the assemblage.

Although the "turnover" of plant species in the CFR is high (Cowling et al. 1989), our results provide little in favour of reserves having to be spaced at intervals of any given distance, as recommended by Burgman (1988) in Western Australia. Burgman contended that a network of reserves located at intervals of less than 15 km is required to protect Mallee vegetation, since substantially different suites of species occur at greater distances. However, every plant assemblage is probably unique, and its composition is possibly the result of chance historical factors. Burgman's (1988) objective of protecting all "suites of species" should be reconsidered. His results do not suggest, as he purports, that the spacing of reserves must be less than 15 km if rare species are to be protected.

We also disagree with Margules et al. (1982) over their contention that there is little value in using species richness in comparing different habitats. The statement is only valid for non-iterative selection procedures. Any procedure that compares the species richness of two habitats, while incorporating the species shared between them and the proportion of species protected when a reserve is allocated to one, will clearly separate out habitats with different compositions of species.

Our proposed reserve configuration does not support the contention of Rapoport et al. (1986) that an optimal "continental" reserve has to be compact, i.e., composed of a few large islands formed by adjacent grid squares, rather than consisting of many isolated smaller islands. This "compactedness" is purported to be an inherent feature of any reserve system that attempts (independently of management) to protect both the most valuable species and a maximum amount of biotic diversity. However, our optimal system requires a relatively small area (9.6% (or 53) of the 550 grid squares containing Proteaceae) for protecting the entire flora. Our selected grid squares show little evidence of aggregation of species, except in the central-south-western part of the system which is rich in both species and endemic species. We would have obtained a "compact" reserve, largely confined to the south-west, had we used the algorithm (a noniterative, species weighting approach) of Rapoport et al. (1986) to delimit our 53 top-ranking nature reserves.

Our results support those of Game & Peterkin (1984). They showed for central England that the optimal method (among noniterative techniques) of protecting total species richness is to preserve sites containing the endemic (rare or restricted) species. Nine out of 90 potential reserves (selected to include all rare plants in central England) included 99% of all other species. Thomas & Mallorie (1985) found in Morocco that areas rich in butterfly species often contained rare species, whereas species-poor areas never contained rare species. In the CFR the incidence of rare species (i.e., both naturally rare species and species impacted by man's activities) is positively correlated with species richness, so that most of the rare taxa also occur in the south-west of the CFR (Rebelo & Tansley MS). If this relationship is generally true it would facilitate reserve selection in areas poorly explored for species. Regions in which species richness is uncoupled from endemicity may require a relatively large proportion of the total area to be preserved in order to protect all the species.

We conclude that the optimal approach for designating an efficient reserve system for maximizing the protection of species richness should be based on identifying areas of high species endemism and richness within recognized biogeographical regions. We thus confirm the utility of these intuitively obvious principles which have been used in the past. Furthermore, approaches based solely on the distribution of rare plants (Kirkpatrick (1983) and zones of minimum overlap of "narrow" endemics (Terborgh & Winter 1983) are demonstrated to be ideal strategies for the preservation of maximum species richness. The significance of these results for the conservation of poorly explored tropical forests is self-evident.

Acknowledgments

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Part 3. Ideals and Priorities

3.3.

Using rare plant species to identify priority conservation areas in the Cape Floristic Region:

the need to standardize for total species richness

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Using rare plant species to identify priority conservation areas in the Cape Floristic Region: the need to standardize for total species richness

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The richness of rare plant species is postively correlated with that of total plant species richness in the Cape Floral Kingdom, South Africa. As a consequence, methods of evaluating priority conservation areas which use the richness of both rare and total species richness underrate species-poor areas with a high proportion of rare species. Grid squares with significantly more rare species than expected relative to the total species richness, based on distributional data of the Proteaceae at an eighth-degree scale, were consistent with those areas reported in the literature to be most in need of protection. The results differed markedly, however, from the only previous attempt to prioritize conservation areas in the lowlands of the CFR, in identifying the Greater Cape Town metropolitan area as most in need of protection based on threatened (i.e. extinct, endangered and vulnerable) plant species. Ranking procedures used to establish priority areas for protection of species must take into account the inter-relationships between rare and total species richness, and other variables. Data from Red Data Books underestimate local threats by not recording geographical variation in threats to widespread species. Where specific taxa are used as an index of threat, heavily impacted areas may be under-represented. With the high numbers of threatened species in the Cape Floral Kingdom we reiterate the need for research utilizing an ecosystem approach with emphasis on identifying keystone species and processes.

The flora of the southwestern Cape Province, South Africa, is both unique (68% endemism) and diverse (8500 species)[1], and has been assigned the status of a Floral Kingdom[2]. The area of remaining natural vegetation in the Cape Floral Kingdom (CFK) is shrinking rapidly: 34% has been lost to agriculture and alien plant invasion[3]. The 1320 Red Data Book plant species for non-karroid vegetation types in the CFK comprise 56% of the southern African total, although the CFK comprises less than 1% of the total area [4,5].

An obvious approach to determining conservation areas is to select areas containing high numbers of endemics[6,7]. However, conservation strategies should take into account, among other considerations, the urgency of preserving areas rich in diversity *versus* those poorer areas most likely to lose their diversity in the near future[8]. Red Data Books (e.g. [4,5]) include both species which are threatened by man's activities and species which are naturally rare. Whereas naturally rare species are an important component of endemicity and species diversity[9], threatened rare species are indicative of the most human-impacted habitats, which urgently require protection.

The only detailed assessment of conservation priorities in the CFK to date [10], confined to the more threatened lowlands of the region, eschewed a total reliance on species composition and emphasized the rarity of component vegetation types. However, the rarity of a vegetation type and its uniqueness, in terms of its constituent species, should be

reflected in the number of rare plant species present in the region[9]. Similarly, the number of threatened species should largely reflect both the impact of man and the rarity of the vegetation type. If a goal of conservation is to preserve species diversity, then threatened species richness should highlight those areas in imminent danger of losing species, and therefore most in need of preservation.

A confounding factor is that more rare species may be expected to occur in areas of higher species richness [9,11,12,](but see [13]). Since both species richness and rarity are commonly used independently when assessing conservation potential[8], areas of low species richness containing a high proportion of rare species are likely to be undervalued when evaluating conservation priorities.

In this paper we compare priority areas in the CFK, based on threatened *versus* natural distributions of Red-Data-Book species *per se* and standardized for total species richness. We evaluate these schemes against the previous assessment of conservation priorities for the region[10].

The study plants

Botanical distribution data, including Red Data Book records[5], are routinely recorded on a quarter-degree grid square basis[14] in southern Africa. This scale is too coarse to reflect the topographical and vegetation changes occurring within the CFK[7] (Fig. 3.3.1). We selected the Proteaceae as a sample of the flora since distributional data exist at a finer scale (eighth-degree) than for other taxa[7]. The Proteaceae family is a conspicuous and characteristic dominant of the CFK and comprises some 331 taxa (species and distinct subspecies, hereafter referred to as species). Furthermore, Proteaceae species richness is strongly correlated to the pattern of species richness in other characteristic CFK families at a quarter-degree scale[7]. Some 124 Proteaceae species (38% of the family) comprise 8% of the Red-Data-Book species for the region[15]. These rare species have been divided into two groups[15], using the categories defined by Synge[16]: 59 species are naturally rare and under no threat at present, and 65 species are categorized as threatened (*i.e.* vulnerable, endangered or recently extinct). As only three species in the data set extend marginally beyond the CFK, the status of all species considered rare herein are not scale sensitive[8] and thus these species are also nationally and internationally rare.

Representativeness of rare Proteaceae species

In order to determine if distributions of Red-Data-Book Proteaceae are typical for that of other Red-Data-Book plant species[5] in the CFK, data were regressed as species per quarter-degree square. Separate data are not available for the karoo and fynbos biomes, so that Red-Data-Book karoo species within the CFK were included in the analysis. Some 80 peripheral grid squares not containing any Red-Data-Book species were omitted from the analysis.

Proteaceae Red-Data-Book species richness was significantly correlated ($r = 0.798$; $P < 0.001$; $Y = 0.112 X - 0.226$; $n = 238$) with total Red-Data-Book species richness at a quarter-degree scale. Two grid squares (3318CD and 3418AB) with a high tally of Red-Data-Book species were significantly underestimated by Red-Data-Book Proteaceae species, despite having the highest incidence of Red-Data-Book Proteaceae.

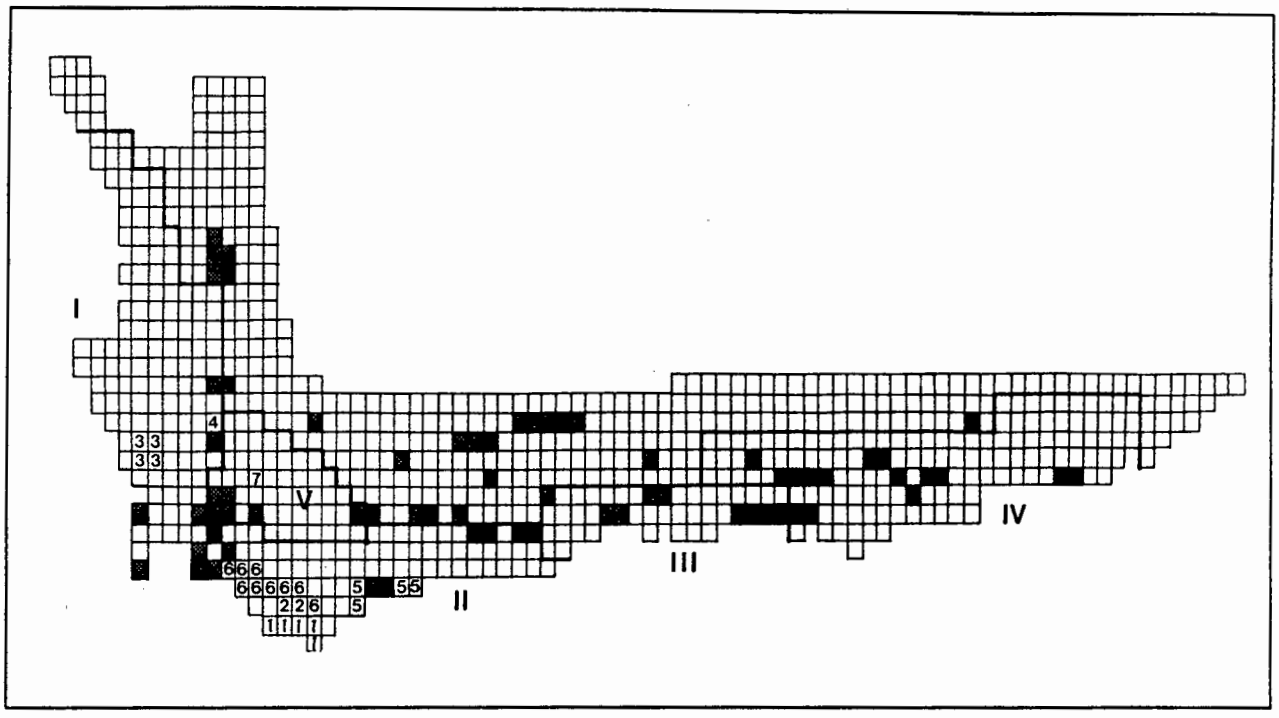

FIG. 3.3.1. Map of study area and grid system used showing areas (1-7) identified as top priority (*i.e.* with a 'conservation merit rating' > 71) in the five regions (I-V) delimited by Jarman[10]. Priority areas are (1) Soetanysberg, (2) Elim, (3) Dassenberg, (4) Elandsberg-Voelvlei, (5) Armscor/Potberg, (6) Bredasdorp Mountains, and (7) Brandvlei. Grid squares with statutory reserves comprising more than half the total area are shaded.

Table 3.3.1. Regression coefficients for rare (square-root transformed) *versus* total Proteaceae species richness. $B_{o,-1}$ represents the recomputed intercept and $B_{1,-1}$ represents the recomputed slope following the deletion of a single case[19]. Standard errors are in parentheses

	Total	Threatened	Natural
n	555	555	555
B_o	0.708 (0.44)	0.713 (0.44)	0.654 (0.27)
B_1	0.0471 (0.0017)	0.0321 (0.0017)	0.0249 (0.0011)
R^2	0.568	0.378	0.495
Adjusted R^2	0.567	0.377	0.494
Range of $B_{o,-1}$	0.706 - 0.711	0.709 - 0.716	0.652 - 0.658
Range of $B_{1,-1}$	0.0467 - 0.0475	0.0316 - 0.0327	0.0244 - 0.0253

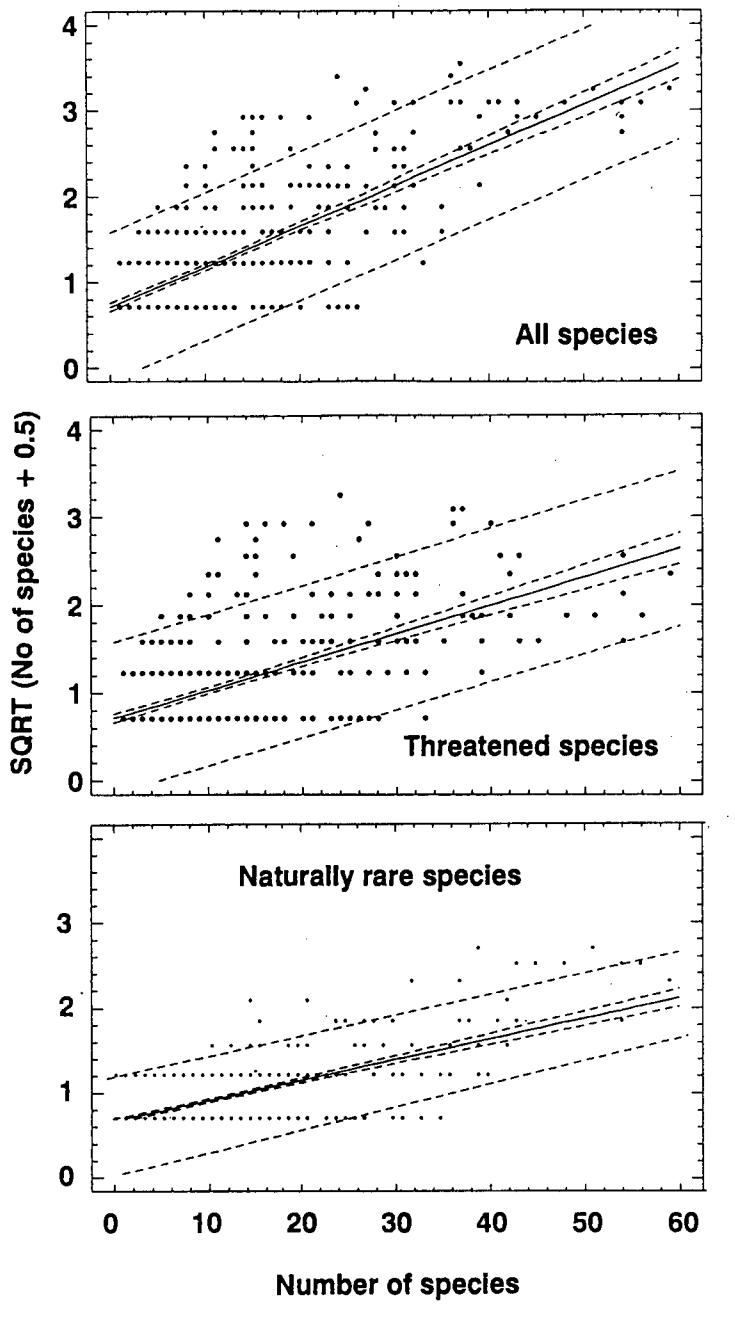

FIG. 3.3.2. Linear regression of the number of rare Proteaceae species (square root transformed) *versus* the total number of Proteaceae per grid square. The dotted lines represent the 95% confidence levels and the dashed line the 95% prediction limits of the regression. Shaded regions comprise the upper 5% of the unregressed data. (a) total rare species; (b) threatened rare species (vulnerable, endangered or extinct); and (c) natural rare species.

An inspection of the total Red-Data-Book plant species per quarter degree grid suggested a strong relationship between total species richness[17] and Red-Data-Book species richness[5]. We therefore compared the Red Data Book data with total species richness, obtained from PRECIS (the list of species held in the Pretoria National Herbarium Computerized Information System[18].) Total rare species richness was significantly correlated ($r = 0.764$; $P < 0.001$; $Y = 0.039 X + 1.94$; $n = 307$) with PRECIS species richness at a quarter-degree scale. Cursory inspection of both regressions suggests that the parameter estimates, particularly the intercept, are probably sensitive to "influential cases" [19] at the more species-rich extreme. However, these do not detract from the significant correlation. Although PRECIS is almost certainly a poor indicator of species richness in the CFK, with endemic species (those most likely to be rare) particularly under-represented[20], it is the only comparable data base currently available.

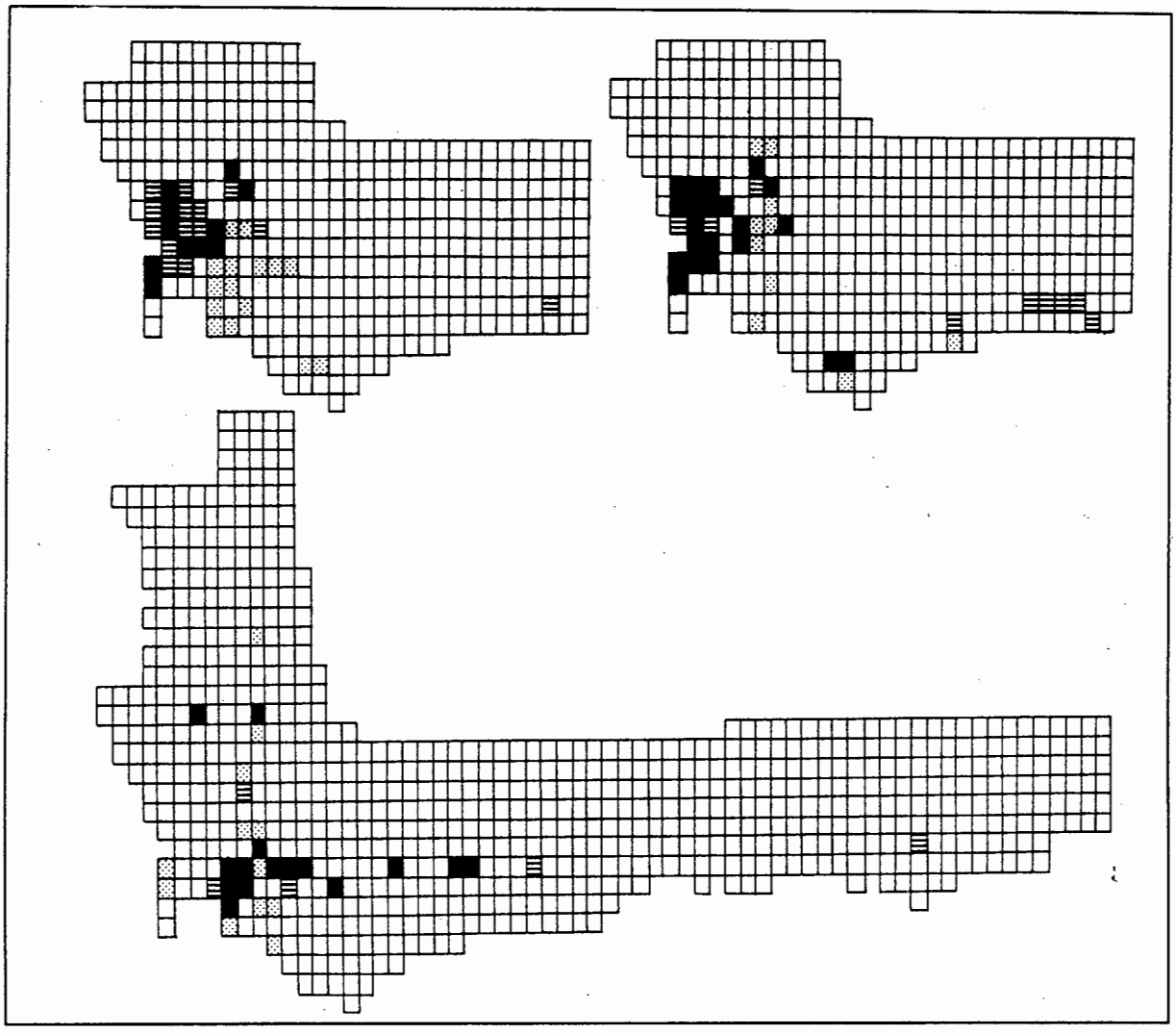

FIG. 3.3.3. The geographical configuration of grid squares containing more rare Proteaceae species than predicted from the distribution of family (see Fig. 3.3.2: horizontal and solid shading) *versus* those in the richest 5% of grid squares (light and solid shading). The areas are identified in the text. (a) total rare species; (b) threatened rare species; (c) natural rare species.

Nodes of rare species relative to total species richness

Using an eighth-degree grid[7], the richness of rare species per grid square was compared with the total richness for the Proteaceae. Regressions were done separately for threatened, naturally and total (both threatened and naturally) rare species, as determined by Tansley[15]. We used a square root transformation for rare species, as data are counts[21]. Grid squares found to lie outside the upper 95% prediction limits for the family were interpreted as having significantly more rare species than expected (Table 3.3.1, Fig. 3.3.2). These grid squares were mapped and distinct groupings were ranked according to the mean of the residuals[21] for the group (Fig. 3.3.3).

Squares with higher than expected total-rare species clustered into two nodes (Fig. 3.3.3a): (1) the northern half of the Cape Peninsula and the Cape Flats to Darling in the north and the foothills of the Mountains in the east; and, (2) the Elandsberg Mountains and associated Fynbos-Renosterveld ecotonal communities on the lower slopes. The outliers were the Albertinia flats (3) and the Brandvlei Dam area near Worcester (4).

Squares with higher than expected threatened-rare species grouped into four nodes (Fig. 3.3.3b): (1) and (2) being the same as for total rare species; (3) the Elim Flats; and (5) the Albertinia flats. The outliers were Brandvlei Dam (4) and the north slopes of the Potberg (6).

Squares with higher than expected naturally-rare species clustered in three distinct nodes, with no concordance to nodes of threatened or total rare species (Fig. 3.3.3c): (1) the Hottentots Holland Mountains (from Hangklip to Du Toits Peak); (2) the Riviersonderend Mountains (centred on Jonaskop, the highest peak); and (3) the Langeberg Mountains (centred around the highest peaks in the east, central and western ranges). Five outliers occurred: two of these (7 & 8) were situations where the rare species were the only Proteaceae species recorded in the grid square; of the remainder (6) coincides with the Elandsberg node for threatened species. Most of the outliers occurred on grid squares with average relief and topography.

Although Red Data Book species contributed to species richness in grid squares, a significant correlation ($r = 0.638$, $P < 0.001$, $y = 0.162 X - 0.07$, $n = 555$) existed between total rare and non-rare Proteaceae species in the CFR. Thus rare species tend to occur in areas rich in non-rare species.

Areas rich in rare species independently of total species richness

Some 263 grid squares, out of the total of 555 occupied by the Proteaceae, contained rare Proteaceae species. About 28 grid squares are equivalent to the richest five per cent of all grid squares in the CFK (Fig. 3.3.2). Clusters of grid squares are ranked by mean richness of rare species.

The richest grid squares for rare species formed a diffuse node centred on the species-rich south-west (Fig. 3.3.3a), but included components of nodes identified using standardized richness. More than half (59%) of the richest grid squares were not identified as significantly rich in rare species if standardized for total species richness.

Grid squares rich in threatened species clustered into three nodes corresponding to nodes 1, 2&4, and 3 identified using threatened species standardized for species richness (Fig. 3.3.3b). In addition, the species-rich mountainous areas adjacent to the first nodes are also identified, with two outliers in the species-rich mountainous areas to the south. About 32 per cent of the richest squares were not identified as significantly rich for threatened rare species if standardized for total species richness.

Grid squares rich in naturally rare species clustered into four nodes, the top three corresponding to nodes 1&2, 3, and 5 identified using naturally rare species standardized for species richness (Fig. 3.3.3c). Most of the additional grid squares identified were on the periphery of these areas, with the exception of the Cape Peninsula, which did not have more naturally rare species than expected based on species richness. About 41 per cent of the richest squares were not identified as significantly rich for naturally rare species if standardized for total species richness.

Comparison of nodes with existing priority areas

These results were evaluated by comparison with Jarman's prioritization for the lowlands of the CFK[10]. The areas used in Jarman's study were based on remaining areas of natural vegetation and are therefore slightly biased against urban areas where few large natural areas remain. We selected only sites scoring greater than 71 on Jarman's "conservation merit scale" (CMS) in each of the five regions[10], and omitted sites containing only Strandveld or Kaffrarian Thicket vegetation. Means were taken for sub-sites when overall scores were not provided. This score is determined largely by the vegetation-type rarity,

but also by habitat diversity, species richness and threatened species richness, and to a lesser extent by size and shape of remaining areas and their degree of invasion and degradation. These regions were ((Fig. 3.3.1: ranked by score in parentheses): South coast lowlands - Soetanysberg Nature Area (1: 80.5), Elim hills (2: 75.7), Armscor area (5: 73.5) and Bredasdorp Mtns (6: 72.5); West coast lowlands - Dassenberg Hills (3: 75.0) and Elandsberg-Voelvlei (4: 74.0); and, Inland valleys - Brandvlei Dam (7: 71.3).

These areas together comprise 28 grid squares, although the identified sites typically occupy only between one-fifth and two-thirds of the area of the grid squares. The predictions based on richest and standardized threatened Proteaceae species concur for 8 and 7 of these grid squares, respectively, although the latter gave a slightly better correlation (Spearman Rank Correlation coefficient[22], r_s = 0.764 and 0.804, respectively, $P < 0.05$).

A major discrepancy between our analyses and Jarman's is that we place the Cape Flats as the top priority area in terms of threatened species. This lack of suitable conservation sites within the Cape Town area, suggests that the Dassenberg Hills should be given a rating far higher than the Soetanysberg and Armscor areas (both of which currently contain a fair proportion of their area as reserves). The valuation of the South Coast sites appears to be inflated, and has been downweighted by the Nakor National Plan Task group[23]. By contrast, a survey of natural lowland remnants in the greater Cape Town metropolitan area have revealed 74 threatened species surviving in the remaining 484 ha of natural and semi-natural vegetation[24]: i.e. the arithmetic equivalent of 15 threatened species per km^2.

Although the threatened species standardized for total species richness (1) gave a better clustering of grid squares, (2) identified fewer conserved areas and (3) identified an additional site (Albertinia flats: not scored in Jarman owing to lack of data[10]), and only concurred with 66 per cent of the richest squares in terms of threatened species, the differences between both approaches are slight. In terms of threats, however, the analysis standardized for species richness gave results consistent with observed patterns of habitat destruction by urbanization, agriculture and alien encroachment confined almost exclusively to the lowlands[24].

By contrast, naturally rare species occur predominantly at high altitudes in areas of high species richness, suggesting that these areas are refugia or speciation centres. Most of the areas rich in naturally rare species are currently protected[7] (Figure 3.3.1), being agriculturally unproductive, with leached soils on steep topography[10].

Evaluation against previous accounts

The use of the distribution patterns of the family as a null hypothesis in order to evaluate distributions of rare Proteaceae species within the Cape Flora appears from *a priori* subjective assessments to be valid. The selection of the Cape Peninsula, Cape Flats, Elim Flats, Elandsberg and Brandvlei Dam as priority conservation areas is consistent with published assessments of these areas (e.g. [5,25,26,27]).

In a cursory analysis of relative richness of rare species per area of biogeographic zone (a combination of biogeographical region and vegetation type), Hall and Veldhuis found that the Elim flats "surprisingly do not figure highly"[5]. Since these grid squares fall on the regression line for Proteaceae species against total Red Data Book species we may assume that the area does not contain a significant preponderance of rare Proteaceae species. A possible reason for the difference in assessment might be a result of our using a constant-area grid system. Biases may be caused by comparing different-sized areas (e.g. 'biogeographic zones', based on a regional sub-division of vegetation types[5]), even when standaridized for area, if rare species are

concentrated within a small portion of a larger area. Similarly, the richness of rare species in an area may be de-emphasized by the sub-division of the area, especially where species are ecotonal to the units under consideration.

Sources of Error

The selection of a taxonomic group as indicative of rare species for any region is fraught with problems. However, in the CFK at the 1:50 000 (quarter degree) map scale, the patterns of species richness are similar among major plant families[7], and the distribution of Proteaceae Red Data Book species reflects that of Red-Data-Book plant species. Whether this relationship would hold for an analysis at a finer or coarser resolution is not known[7].

Because Proteaceae are largely confined to Fynbos vegetation types in the CFK[7], we appreciate that we are under-representing the remaining vegetation types. Nevertheless, Renosterveld, Afromontane Forest and Thicket vegetation types do not contain very many Red Data Book species relative to Fynbos[5], despite Renosterveld having been reduced to 6% of its original area by agriculture[28]. This suggests that either Renosterveld was transformed before botanical collections began,[5] or that Renosterveld plant species tend to be widespread with few localized endemics. Afromontane Forest and Thicket are considered to be depauperate isolates of a richer and more extensive eastern flora[29], and may therefore be expected to contain few endemics[1,29]. Although we appreciate that the conservation of the rapidly disappearing, remaining Renosterveld is an urgent priority, the distribution of rare species suggests that conservation of Fynbos types within Cape Town and environs is even more urgent.

Another potential source of error in using a single taxon as an indicator of total threat is that in some areas the taxon may be impacted to such a degree that there are insufficient species to reflect the true extent of the threat. Thus, squares 3318CD and 3418AB (both in the Cape Peninsula area) were identified as significantly under-estimating total Red-Data-Book plant species richness, despite being among the richest squares in terms of Proteaceae species in the CFK. Where comparisons of a representative taxon with total richness cannot be undertaken, such errors will be transparent.

A further problem encountered herein is exemplified by six species of Proteaceae which are threatened in the Cape Peninsula (*viz. Aulax cancellata* (E), *Leucadendron rubrum* (V), *Leucospermum vestitum* (X), *Protea burchelli* (X), *P. grandiceps* (E), *P. scolymocephala* (V)). None of these species are included in the regional list of threatened plants for the region[27], because they are common and not threatened outside the region. Thus widespread species threatened in only a portion of their distribution range are seldom included in Red Data Books. Regional Red Data Books, which explicitly include locally threatened species, are therefore urgently needed if priority conservation areas are to be accurately identified, especially if the preservation of genetic diversity in widespread species is a consideration. If these data books are to embrace the concept of biogeographical regions[17,30], these regions must be as small as 500 km^2 in the southwest of the CFK.

It is uncertain whether Regional Red Data Books would redress the problem of under-representing rare species in heavily impacted regions, or merely show that the biota are far more stressed than previously thought. In the case of the CFK, we suspect the latter. Although compiling regional Red Data Books will require a large investment in research, it is more feasible than the autecological studies of all species as suggested by Simberloff[31], and would highlight those species most in need of autecological studies. The use of administrative boundaries devoid of biological units for regional Red Data Books would result in high numbers of "peripheral" rare species (with distribution ranges chiefly beyond the district).

Peripheral species elevate species richness and when considered as rare in the region complicate the estimation of rarity[8]. This problem should be relatively infrequent if regions are based on biogeographical zones.

Conservation Implications

The distribution of representative sites for preserving biotic diversity has been based on a variety of criteria[8], and although species richness and rarity rank high among criteria used, an association between total and rare species richness has not been identified previously. As a consequence, areas rich in both common and rare species tend to be over-evaluated, relative to species-poor areas with a similar richness of rare species. As habitats are impacted by man's activities, threatened species will increasingly contribute to the total species richness. Unless efforts are made to identify relatively species-poor areas containing a high proportion of rare species, such areas may not be identified as important. Fortunately, any evaluation that simultaneously considers habitat rarity and the conservation status of individual species should redress this problem to some degree[32].

The high species richness of Fynbos vegetation and the large number of threatened species miligates against Simberloff's[31] approach of basing conservation management on the autecology of target species. Even if the autecology of a sizeable proportion of threatened species were known, there is no protocol for extrapolating results to the unstudied species[33]. Furthermore, the genetic and demographic consequences of small populations[34,35] may differ between naturally-rare, local endemics and species with formerly extensive distribution ranges currently reduced to local remnants. Thus ecological studies undertaken in natural populations may not be applicable to threatened species reduced to small, local nature reserves[36]. Effective preservation strategies for threatened species therefore may involve more intensive management than that required for naturally rare species. We therefore concur with Bond [33] in advocating an ecosystem approach, with research emphasis placed on identifying keystone species and processes[37].

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Synthesis

Synthesis

In the introduction I reviewed the available data bases for ascertaining conservation options in the Cape Floristic Region (CFR), and outlined the logistic constraints imposed by these data bases. But what has been achieved and what remains to be done? How far are we from resolving the theses outlined earlier?

Thesis 1: A reserve network can be designed so that a Minimum Viable Population of all target species is not required for any specific reserve, provided that corridors are available.

The conservation implications of the theory of island biogeography crystallized conservation from the realm of art and experience to a scientific discipline (Soule & Wilcox 1980). Although the SLOSS debate (Jensen 1987, Simberloff 1988) is largely in abeyance, occasional examples still appear in the literature and illustrate that, depending on the system under study, either two or one reserves of the same total area will preserve more species. Right from the start of the debate it was appreciated that not all species require preservation and that conservation efforts should be aimed at those species most at risk due to habitat fragmentation. To this end the empirical J-function (Diamond 1975) was proposed, but soon became replaced by more theoretical concepts such as maintaining minimum viable population (MVP) sizes, inbreeding depression and heterozygosity and gene flow (Soule 1986). The upshot of this debate was quite simply that the bigger the reserve, the more efficiently it would preserve the higher trophic levels and thus maintain more integral ecosystems.

Although no research on SLOSS or MVP was undertaken within the CFR, the debate was followed with interest locally (Siegfried & Davies 1982, Hall 1984), and resulted in the concepts being applied to species within the CFR (Kruger 1977). As a consequence, even though it was generally acknowledged that reserve size must be determined by the conservation goals, emphasis was continually placed on the concept that "bigger is better", and focussed on individual reserves rather than reserve systems. This resulted in little progress in the conservation of the lowlands of the CFR (Section 1.1). Tracts of land large enough to justify conservation based on these principles no longer exist. This provided a 'valid reason' for conservation officials to ignore the threatened and poorly preserved lowlands of the CFR and invest their monies in large reserves which could be acquired at far lower cost. This has resulted in the problem that threatened areas in need of conservation are being ignored in favour of areas which are effectively already preserved because of their aridity, inhabitability and low agricultural potential (Section 1.1).

This unacceptable situation prompted my adopting a holistic approach, in which I appraised the conservation goals for the entire region, not just for single reserves. For instance,

do we need to preserve large mammals in all CFR reserves? The minimum reserve size for preserving minimum viable populations of higher-trophic level herbivores (e.g. Mountain zebra) and carnivores (e.g. Leopards) within the CFR appears to be about 10^5-10^6ha. Reserves of this size class occur in most mountain centres of plant endemicity in the CFR, although very few occur in the lowlands. Furthermore, all these large mammal species, with the exception of the endemic Bontebok (now well preserved in many reserves), are all better preserved in areas with a higher carrying capacity than Fynbos, such as the Karoo and Savanna Biomes (Section 1.1).

Consequently, I have argued that preservation in the CFR, with the exception of a few large reserves still required in key areas (Sections 3.1 and 3.2), should focus on obtaining small reserves aimed specifically at preserving those remaining habitats, and, plant, small-vertebrate and butterfly species which urgently require preservation (Sections 2.1 and 3.3). Contrary to current management perceptions, reserves as small as 5 ha should be able to preserve communities of plants (Cowling & Bond in press), provided that ecosystem processes, chiefly the fire-mediated disturbance-recruitment regime, and alien plants are adequately managed (Section 1.1). This is possible in Fynbos because, whereas the distribution of plant populations is determined by substratum and water regime (rainfall and drainage), recruitment and population turnover are determined by large-scale fire perturbations which can readily be controlled and altered. In terms of landscape ecology (Turner 1989), although species distributions are influenced at a local scale, their population dynamics are influenced primarily by broad-scale perturbation events. Provided that the perturbation events are adequately managed, then reserves at the scale of local patches appear to be a practical option in Fynbos of the CFR.

Fortunately, Fynbos patch dynamics is such that vegetation units often occur in discrete habitat patches (Cowling & Bond in press), with minimal seral succession in species composition (Rebelo & Jarman 1987), so that provided fire and water regimes are maintained, abrupt reserve boundaries are suitable for plant preservation. Thus apart from a fire-buffer zone, most Fynbos reserves can probably be preserved with very narrow boundary zones. This also increases the viability of very small reserves.

Owing to the high numbers of threatened species, *ex situ* preservation is only feasible for a small proportion of plant species. Seed banking may offer an alternative solution, but large numbers of seeds are not usually available from threatened plant populations (Section 1.1).

My holistic approach is based on several assumptions which require investigation. Firstly, it assumes that the highly mobile large mammals are able to move between reserves. For Mountain Fynbos with its low agricultural potential and importance as water catchment areas, the extensive contractual reserves linking statutory reserves appear to satisfy this condition (Section 1.1).

Secondly, it assumes that ecological processes in Mountain Fynbos are independent of the conservation status of Lowland Fynbos and other vegetation types. This may not be so, but the matter does not lend itself to detailed study: too little of the lowlands remain to enable an investigation into the interactions which may have existed between mountain and lowland ecosystems 200 years ago. However, it is imperative that we try to predict which elements within the ecosystem are susceptible to disruption. For Fynbos plant species it appears that dispersal and pollination syndromes are sufficiently opportunistic to survive insularization. However, pollinating birds may be prone to loss of seasonally important food sources, which would result in a decrease in numbers of avian pollinators available to plants

(Rebelo 1987). Bird pollination is associated with large distribution ranges in the Proteaceae (Section 2.1), and although insect pollination may adequately compensate for a decline in bird numbers, it appears that outcrossing distances might decrease drastically in these plant species. The significance of such a change is unknown. Renoster Shrubland has been historically degraded and it is probably no longer possible to reconstruct this ecosystem in its entirety. The other vegetation types were not considered in this thesis, but their interactions with Fynbos and Renoster Shrubland also require attention.

Lastly, studies are required to determine the effect of insularization in Fynbos. The two studies done to date (Bond *et al.* 1988, Cowling & Bond in press) suggest that regional differences in minimum reserve size may vary considerably. An understanding of the regional variation in spatial pattern of recruitment regimes appears to be the crucial factor requiring investigation. Additional questions include: What processes are likely to disrupt the ecology of Fynbos in small reserves? How should fire regimes, water-table fluctuations, nutrient-imports and recreation be managed? What are the maximum distances and minimum food requirements for pollinators to visit small reserves? How does patch dynamics vary over the CFR, especially between mountain and lowland sites, and how does this relate to minimum reserve and boundary zone dimensions?

Many of these problems can be tackled piecemeal in small reserves as individual problems manifest themselves. What is important for conservation in the CFR is that the relevant authorities be given the necessary guidance on priorities within the region. Authorities must be forced simply to admit that the only reason why the lowlands are not being preserved is the high cost of the land. Only then will public and official attention be given to the high conservation priorities and the contentious acquisition (Kahn 1990) of huge tracts of land (often managed by landowners on ecologically sound principles) be averted.

Thesis 2. Any management programme based on single species preservation will be to the detriment of many other threatened species. Management programmes aimed at preserving biotic diversity should be geared to maintaining natural ecosystem processes.

Red Data Books and their equivalents have proved to be a remarkable ally to conservation agencies (Ferrar 1989). Regionally, they have documented the extent to which species have been threatened by mankind's activities. In better known groups they have identified the relative importance of threats to species. And yet, these books have largely been used as inventories and for public support. I have been unable to find many analyses of the geographical distribution of threatened species, or syntheses evaluating either this or the patterns of threats between different Red Data Books within a region. I hope that the utility of this approach is illustrated in section 2.1.

Perhaps this lack of synthetic use of Red Data Books stems from their origin in northern temperate regions where legislative boundaries bear no resemblance to ecological regions. Perhaps the relatively depauperate temperate floras have encouraged species-specific conservation campaigns. Even for California one gets the impression that large

concentrations of rare species seldom occur (Holland 1987, Kranz 1987), except perhaps on specific unusual formations (Kruckeberg 1987). But even in the first world, conservation programmes aimed at specific "target species" have their problems (Rice 1990).

Locally, the unquestioning use of target species resulted in the deproclamation, in 1990, of two small provincial nature reserves on the alleged basis that they were not preserving minimum viable populations of the Geometric Tortoise, for which purpose they were originally proclaimed. It was apparently forgotten that these 'pocket handkerchief' reserves were more than large enough to protect some of the last viable populations of several plant species typical of the Waveren valley (Wood 1991).

It proved too arduous to undertake a specific study of the relative merits and demerits of "target species" *versus* "ecosystem-orientated" conservation approaches. However, it is apparent from a comparison of Red Data Books, that, for the CFR at least, the majority of rare species are symptomatic of the threats to their habitats (Sections 2.1 and 3.3). The use of target species may be ideal for engendering public support in order to obtain or proclaim reserves (Ferrar 1989), but it is not the ideal approach to use for the management and maintenance of ecosystem function. The mis-management of Fynbos in order to maintain herbivores belonging in Renoster Shrubland (Sections 1.1 and 2.1) is a classical example of how the lack of an ecosystem perspective, coupled with a resolute determination to preserve target species, can result in the degradation of a unique ecosystem. What makes the situation tragic is that the majority of target species were already preserved in countless other reserves throughout the continent. Obviously, a global approach to conservation, including international cooperation between reserve and zoo authorities, is essential.

Thesis 3. Rarity in plants is determined largely by short dispersal distances and low persistence. Many of the theoretical correlates of small population sizes (loss of heterozygosity, inbreeding depression, stochastic and demographic instability) do not operate to make species rare, but only operate once species have become rare.

In Fynbos vegetation, three things are strikingly different from other CFR and adjacent biome vegetation types. Firstly, plant-animal interactions are dominated by the low community biomass of herbivores, insectivorous birds (and therefore presumably insects) and vertebrate seed dispersers, the only noticeable exception being pollinating birds (Rebelo 1987). Secondly, a large proportion of the flora is myrmecochorous, presumably in an attempt to remove nutrient-rich seeds from predators, whereas another strategy, serotiny, in which seeds are stored in the canopy until a fire occurs, is confined to Fynbos (Bond and Slingsby 1983). These features appear to operate in other nutrient-poor and heathland ecosystems (Rebelo & Jarman 1987, Westoby *et al.* 1990). Thirdly, a large proportion of plant species, which dominate the vegetation in terms of cover, are killed by the dominant perturbation event, fire, and survive only as seeds (Rebelo & Jarman 1987).

Consequently, it appears relatively simple to predict what features of the environment will

determine rarity in a species. Thus widespread species will be those able to survive the fire as adults (high persistence, low susceptibility to extinction following unfavourable germination conditions following a fire) and those with better than average seed-dispersal distances. Because recruitment only occurs after fires which occur at 10-60-year intervals (Rebelo & Jarman 1987), and seed dispersal distances in myrmecochorous species are of the order of one to two metres (Bond & Slingsby 1983, Westoby *et al.* 1990), it should take a myrmecochorous species roughly 150 000 fire events, or 4 million years, to expand from a central location to throughout the 750 km extent of the CFR. For serotinous species, with seed dispersal distances of several hundred metres, the period is likely to be much shorter (4 000 fire events or 100 000 years). Furthermore, Fynbos is not continuous as considerable barriers exist to colonization of the entire CFR. Thus it was logical to expect that serotinous species should have widespread distribution ranges *versus* more localized myrmecochorous species; and resprouters should be less likely to speciate or go locally extinct and therefore should be more widespread than non-resprouters (Section 2.2). In other words, for Fynbos current concepts of rarity (Drury 1974, Kruckeberg & Rabinowitz 1985, Rabinowitz *et al.* 1986) might be simply related to obvious and well-researched ecological traits of species.

Two problems to this argument exist. Firstly, colonization rate is not dependent on modal dispersal distances, but on unknown maximum dispersal distances. Thus the periods of colonization presented above may not even be correct to an order of magnitude. However, ant-dispersed seeds are unlikely to travel as far as wind-dispersed seeds. Secondly, all species differ in age. However, since resprouters are more persistent than non-resprouters, their longer generation times suggest that on average they may be older than more-rapidly speciating non-resprouters. A corollary is that there should be more species of non-resprouters with a smaller average distribution range.

To my surprise the data for the Proteaceae matched the predictions far in excess of significance levels I had anticipated. Note though that at the rates proposed above, a European equivalent of Fynbos flora would still be sitting in the Alps in its attempted recolonization of areas glaciated during the Pleistocene (primarily because recruitment in Fynbos is fire mediated: there are very few annual plant species in Fynbos (Rebelo & Jarman 1987)). Presumably, the more complex the regeneration strategies within a vegetation type, especially where compounded by seral stages, the more complex the interplay between dispersal, pollination and rarity. To this end, nutrient-poor ecosystems may still shed considerable light on recruitment-independent correlates of rarity. Specific gaps which need to be filled include the correlates of rarity in minute-seeded species not encountered in the Proteaceae (Ericaceae, Orchidaceae), and how rarity relates to patch-dynamics and species richness in the CFR. Studies of population structure at the landscape level are also required: in particular habitat specificity needs to be investigated at a more detailed resolution (various type of seeps, rocky outcrops versus sand patches, exposed versus wind-sheltered microhabitats, etc.).

It became apparent whilst formulating the expected correlates of rarity, that no ecological traits could explain why species should be so rare that stochastic processes determined their survival. However, certain traits were distinctly disadvantageous in extremely rare species (e.g. dioecy, where sex ratios are an additional burden relative to cosexual species). However, lack of data prevented a more detailed exposition of the factors affecting very rare species, despite the fact that many such very rare species occur in the Proteaceae (Section 1.1). Given the lack of studies of minimum viable populations in plants, possibly because a potentially large proportion of the population

may exist as propagules, emphasis should be placed on relating the dynamics of seed numbers and dispersal to parent-seedling ratios over recruitment events. Research into the conservation management of Fynbos is severely handicapped by the long intervals between recruitment events. Therefore, techniques for extrapolating studies of spatial variation in ecosystem parameters to results pertinent to temporal variation require attention. More importantly, factors limiting extrapolation of studies of small populations of common species to those of rare species require elucidation.

Thesis 4. A reserve network based on the interpretation of (even a rudimentary knowledge of) biogeographic zones, vegetation types or turnover rates (delta diversity) will preserve a considerable proportion of the biotic diversity, provided that preservation and priorities are emphasized in centres with high endemism and species richness.

Five studies stand out in my mind as contributing more to conservation biology than all those involved in the endless debates on SLOSS (Jensen 1987, Simberloff 1988), MVPs (Gilpen & Soule 1986) and reserve selection procedures (Margules & Usher 1981). These papers (Kirkpatrick 1983, Terborgh & Winter 1983, Diamond 1986, Purdie *et al.* 1986, Myers 1988) attack the core of the conservation dilemma: where should reserves be situated to maximally preserve biotic diversity? They did not address how many reserves might be required. They hardly mentioned the size of these reserves. They simply acknowledge the fact that we currently have insufficient data or time (and no manpower or resources to collect such data) to plan ideal nature reserve systems, but yet the immediate planning of nature reserve systems is required if the bulk of biotic diversity is not to be lost. All propose that reserve systems should concentrate on centres of endemism and species richness in a representative array of vegetation types/biogeographic zones.

Having a tolerably good data base for the Proteaceae of the CFR (Appendix 3), I attempted to test whether these intuitively sound assumptions were valid. More specifically, I was interested in how turnover between regions would determine the position and number of reserves to preserve as many species in as small an area as possible.

Initial manual exploration of reserve selection algorithms (Section 3.1) rapidly progressed to the writing of a programme (Rescue: Appendix 5) to process the data. This allowed a variety of algorithms to be explored, as well as a bootstrapping method of assigning null models to assess the efficiency of different reserve configurations (Section 3.2). During this process, Margules *et al.* (1988) and Pressey and Nicholls (1989a,b) published their iterative procedures for southern Australia.

The exploration of the null models allowed many published assumptions and assertions concerning the configuration of efficient reserve networks to be assessed (Section 3.2). Specifically, we found little evidence for reserves being spaced at equal intervals or being compact areas centred on high diversity. Rather we found that the best method was to preserve sites containing endemic (rare or geographically restricted) species. Under these conditions representative geographical populations of

widespread species were usually preserved. A further (expected) result is that richer biogeographic zones require more reserves. These results lend empirical support to the techniques employed in the earlier studies outlined above, and suggest that an efficient reserve network can probably be based on a rudimentary knowledge of centres of endemism and species richness.

In retrospect, I still have not resolved my original dilemma of how an optimal reserve configuration (to preserve all species in a minimum area) is determined by species turnover. Intuitively, in a truly homogeneous environment, number of reserves comprising a given area is irrelevant (Lahti & Ranta 1986). In the real world two reserves should be better than one. But what exactly is the relationship between geographical variability and the number and placement of reserves (Higgs 1981)? Obviously, preserving local endemics will preserve all the common species. Is it always true therefore that a reserve configuration preserving endemics will preserve maximum species richness? Do regions with a very high species richness but very low endemicity exist, where this principal may not hold? Preliminary data analysis for the CFR suggest that choosing reserve systems on unpreserved species richness is as effective as selecting on endemic species: the final configuration is similar - only the ranking of reserves within the system differs. It is my intention to continue exploring this issue.

Thesis 5. Criteria used to assess wildlife conservation potential must be analyzed for correlations among variables if an objective ranking is desired.

Early attempts at ranking areas for potential nature reserves lacked logical rigour. Thus a haphazard collection of attributes including geology, geomorphology, biodiversity and human perception and needs were assigned to candidate areas (Margules & Usher 1981), one feels often in an attempt to give credence to the author's subjective viewpoint. Little or no attempt was made to check for correlations between variables (for instance, relief, geological diversity and species richness), so that a ranking could be deliberately or unintentionally biased towards a particular area by simply selecting suitable attributes. Similarly, ranking procedures and criteria can be varied to provide almost any "required" outcome.

Although the need to cross-classify attributes is now recognized, not only in reserve selection procedures, but also in species definition (*e.g.* allometric induced correlates in diverse plant organs (Bond & Midgley 1988)) and studies of ecological traits (Givnish 1987). Within the CFR, only two exercises at ranking conservation priorities have been undertaken. Jarman (1986), in an evaluation of the lowlands, did not check for correlations between variables used to rank sites. Similarly, Hall and Veldhuis (1985) could not explain why the Elim district, which subjectively is an obvious high priority conservation area, did not feature highly on their ranking of sites by number of Red-Data-Book species per area.

Both these studies failed to appreciate that the incidence of rare species is dependent on the total species richness. Unless this factor is taken into account, species-rich areas containing proportionately very few rare species, are going to be ranked above species-poor areas with proportionately very many rare species. Thus the ranking will not identify the areas with highest threats (i.e. with proportionately more rare species), but merely those with more

species (and therefore more rare species). It is thus essential to ensure that the variables chosen (*a priori*) for consideration reflect the component of environmental diversity that it has been selected to achieve.

This can also be achieved by using many environmental attributes and a multivariate technique. However, an economically more reasonable approach is to select *a priori* variables that adequately measure a precisely defined attribute deemed to be important. The *post-priori* selection of a particular multivariate result (*i.e.* a particular plane in a combination of axes from a biplot) from a diverse collection of ill-considered attributes, achieves nothing more than a description of the researcher's subjective assessment (no matter how valid this may be). Only by the careful *a priori* selection and definition of criteria, with subjective assessments spelled out before the analysis (as hypotheses to be tested), can progress, as opposed to a mere description of *a priori* opinion, be obtained.

Codicil

Considerable progress has been made over the last decade in identifying priority conservation areas, determining minimum reserves sizes and in describing the nature and extent of threats operative in the CFR.

However, in my opinion, conservation research has far outstripped its pragmatic usefulness in the CFR. The major conservation agency in the region is currently unable to achieve its mandate to preserve biotic diversity due to lack of funds, ineffective administration, and outdated policies. As a consequence of the current political changes, financial and manpower resources will probably be directed towards achieving the urgently required urbanization, industrialization and education of South Africans. Although tourism and regional water requirements will ensure some preservation of natural resources in the CFR, conservation will be relegated to a minor issue. That is, unless international financial support and pressure are brought to bear on the region to preserve its biological wealth.

Now is the time to forget South Africa's pariah past. Those who supported sanctions against South Africa now have a moral obligation to ensure that the country does not decay into third-world anarchy. It is insufficient to point out what should be done: biologists must extend themselves to achieve their conservation goals (Raven 1990).

After all, there is more at stake in the world than just the tropical forests. The fate of one of the world's floral kingdoms may hang in the balance.

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Addendum One:

The preservation of plant species in the Cape Floristic Region: problems with the available data bases for the Riversdale Magisterial District.

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The preservation of plant species in the Cape Floristic Region:

problems with the available data bases for the Riversdale Magisterial District.

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Abstract

An evaluation of optimal reserve networks requires a data base containing lists of species currently preserved and regional lists for remaining areas. We evaluated two such data bases for the Riversdale Magisterial District: PRECIS and a catalogue, published in 1984. Although the catalogue was more accurate than PRECIS, having an error of 7 versus 26 percent of the species listed in the district, neither is adequate for conservation planning purposes. We propose that regional herbaria should be catalogued on data bases inter-compatible with a Geographic Information System, that the Catalogue should be updated, computerized and more detailed distribution and rarity data included, and that PRECIS must be thoroughly verified. Only then can these data bases be of use to planning conservation strategies in the Cape Floristic Region.

Keywords: checklists, conservation, Geographic Information Systems

Introduction

The South African nature-reserve system did not develop according to any preconceived strategy to maximize biological diversity (Siegfried, 1989). In this it parallels reserve systems in other parts of the world (Terborgh & Winter, 1983). With 8600 of the subcontinent's 24000 plant species, the Cape Floristic Region (CFR) is one of the world's conservation priorities (Bond & Goldblatt, 1984). However, the floral richness of the CFR requires that reserves be situated carefully so that maximum biological diversity is preserved (Rebelo & Siegfried, 1990; Rebelo & Siegfried, subm.). Additional reserves are required urgently, especially in the lowlands (Jarman, 1986), if the floral diversity of the CFR is to be preserved. Ideally, an evaluation of possible reserve networks should involve a two-step process: after determining which species are adequately preserved in the existing reserve network, those areas containing the highest concentrations of unpreserved species should be targeted for preservation (Rebelo & Siegfried, subm.). However, comprehensive checklists of plant species exist for only nine per cent of the 582 publicly-owned nature reserves in South

Africa (Siegfried, 1989). Furthermore, few data bases exist for determining the location of potential nature reserves so as to encompass areas with concentrations of species or specific groups of species. Two publicly-accessible data bases exist for the CFR: PRECIS (Gibbs Russell & Gonsalves, 1984) and Bond and Goldblatt (1984) hereafter referred to as the "Catalogue".

The aim of this paper is to assess the effectiveness of these two data sources as bases for assessing conservation requirements in the CFR. We have chosen the Riversdale Magisterial District since this region has been identified as requiring additional surveying for conservation priorities (Jarman, 1986, Burgers *et al.*, 1987); was the focus of a vegetation classification exercise (Cowling *et al.* 1990, Rebelo *et al.*, in press); and is currently the focus of conservation efforts (T. Robinson, National Parks Board, pers. comm.). Botanically the area was thoroughly explored at the turn of the century (Muir, 1929) and a field guide (Bohnen, 1986) was published recently.

Methods

All species of seed plants with distribution ranges encompassing the Riversdale Magisterial District were extracted from the Catalogue. We are aware of 16 Erica species omitted from the Catalogue owing to a page omitted in compilation. Species recorded in the Catalogue as occurring in adjacent magisterial districts (MD) (Swellendam, Heidelberg and Mossel Bay) and in areas containing similar habitat types (Bredasdorp MD) were checked in local herbaria (BOL, NBG) to ascertain whether specimens were recorded for the Riversdale MD.

PRECIS listings for South Africa 1:50 000 grid squares 3321CC, CD, DC, 3421AA, AB, AC, AD, BA, BC and BD were used to compile a list of species in the Riversdale MD. These grid squares correspond to the magisterial district fairly closely. The area largely comprises the coastal lowland and mountain vegetation, although some Karroid Shrubland on the north slopes of the Langeberg are included. The list did not distinguish between species collected in the wild and those collected from cultivated plants. This analysis excludes all specimens for which quarter-degree grid squares could not, for whatever reason, be assigned. In our analysis we specifically ignored additional ungridded geographical data such as magisterial districts: biogeographical regions which are the focus of conservation efforts (Rebelo and Siegfried 1990) seldom follow legislative boundaries.

Only the extreme distribution ranges of species are provided in the Catalogue. Consequently, species in the Catalogue not specifically recorded as occurring in the Riversdale MD, and not recorded as present in the PRECIS list, were checked in the local herbaria for specimens in the district. The PRECIS and Catalogue lists were compared and discrepancies were categorized by the nearest MD given in the Catalogue. The final checklist (Cowling *et al.*, 1990) is available from the authors.

The number of species with conflicting distributional data was far too large to undertake the originally planned evaluation into the source of the incongruity for each species. The Proteaceae were therefore chosen as a representative group to delimit the sources of error which a compiler of regional lists must contend with. The Proteaceae is especially suitable in having genera revised both before and after the Catalogue was published, as well as a genus as yet unrevised. Thus, it should include a range of possible sources of discrepancies between the data bases, including new distribution records and differing classifications. Furthermore, Proteaceae species richness per quarter-degree grid square is significantly correlated with that of other major CFR taxa (Bruniaceae, Ericaceae, Penaeaceae, Restionaceae, Rutaceae, *Aspalathus*, *Muraltia*) (Rebelo & Siegfried 1990), and is thus representative of problems

which may pertain to the CFR. We used a detailed listing of all fields for each specimen in PRECIS (three additional Proteaceae species were added to PRECIS for the MD between compiling the checklist and obtaining the listings) to classify the discrepancies into: those that were incorrectly coded for locality based on the locality description (locality miscodes); and those, with localities in the district and which are known to not occur in the district, but which might readily be mis-identified with other species present in the Riversdale MD (ID/sp. no. miscodes). We used collectors' sequences, incongruous localities and species' habitat tolerances to support our classification. Most discrepancies could readily be assigned to either locality or ID/sp. no. miscodes, although we acknowledge a detailed inspection of specimens by a Proteaceae taxonomist would have strengthened our case for the mis-identified category.

Results

A total of 2 701 species of seed plants are recorded as occurring in the Riversdale MD (Fig A.1). PRECIS and the Catalogue contribute 1984 (73%) and 1969 (73%) species, respectively, with 663 PRECIS species (33% of PRECIS list) not occurring in the region according to the Catalogue and local herbaria. Some 345 species (18% of the Catalogue list), whose distribution ranges include the Riversdale MD according to the Catalogue, did not have specimens from the district in local herbaria or PRECIS.

Some 92 species are, according to the Catalogue, endemic to the district. An inspection of these records for *Erica* (Dulfer, 1964; Baker & Oliver, 1967), *Watsonia* (Goldblatt 1989) and Proteaceae (13 species), revealed that two of the eight *Erica* species and both of the *Watsonia* species are not endemic to the region as reported. Two of these errors are probably due to mis-interpretation, where entries such as "limestone hills, Riversdale" should be broadly interpreted as all limestone hills along the entire south coast from Bredasdorp to Mossel Bay MD; one is an error, and one is a range extension owing to the discovery of a new population on the Swartberg. Of the species recorded as endemic to the Riversdale MD in the Catalogue, 51 (55%) were recorded in PRECIS.

Some 108 alien species are recorded from the district. Bond and Goldblatt (1984) did not catalogue 46 (43%) of these, presumably because they were considered non-invasive in natural vegetation in the CFR.

Some 122 species, not specifically recorded from the region in the Catalogue or PRECIS, have

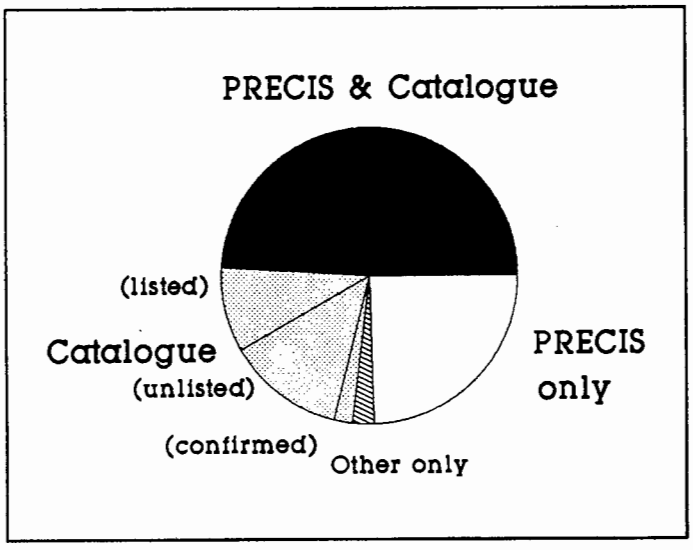

Figure A.1 The source composition of the 2701 species in the Riversdale Magisterial (MD) checklist. The Catalogue data are separated into: those shared with PRECIS; those listed from the MD (listed); those whose distribution ranges include the MD although were not listed specifically as occurring there (unlisted); and "unlisted" species which were confirmed from the MD in local herbaria (confirmed). "Other" refers to species recorded in Bohnen (1986) or local herbaria, but were not present in either PRECIS or the Catalogue.

specimens in the local herbaria (50 species) or are listed in Bohnen (1986: 72 species). Of these, 68 supposedly do not occur in the region according to the Catalogue, 51 of these are from Bohnen (1986). We have not considered the possible source of these errors.

The closest distribution ranges of the 731 species listed as not occurring in the Riversdale MD in the Catalogue are shown in Figure A.2. Some of the 127 species in the neighbouring magisterial districts may be genuine range extensions. However, it is unlikely that many of the 296 species from intermediate and 125 species from distant magisterial districts include any range extensions, with the possible exception of species from coastal sands and limestones in the Bredasdorp MD. Some 54 taxa recorded as endemic to another magisterial district in the Catalogue were recorded from Riversdale MD in PRECIS. Featuring strongly were Bredasdorp MD (26%), Cape Peninsula (15%), Caledon MD (13%) and Clanwilliam MD (9%) (Fig A.2).

Of the 84 Proteaceae species recorded for the Riversdale MD, 26 (31%) are outside their distribution ranges according to the Catalogue (Table A.1). This is consistent with the proportion obtained (33%) for the MD based on the entire PRECIS data base. Current knowledge suggests that the Catalogue is correct in 77 per cent of the conflicting cases, PRECIS is correct in only 15 per cent, and neither is correct (*viz.* the distribution range is larger than stated in the Catalogue, but the species is also not present in Riversdale, despite being recorded as so in PRECIS) in 11 per cent of cases. Four Proteaceae species,

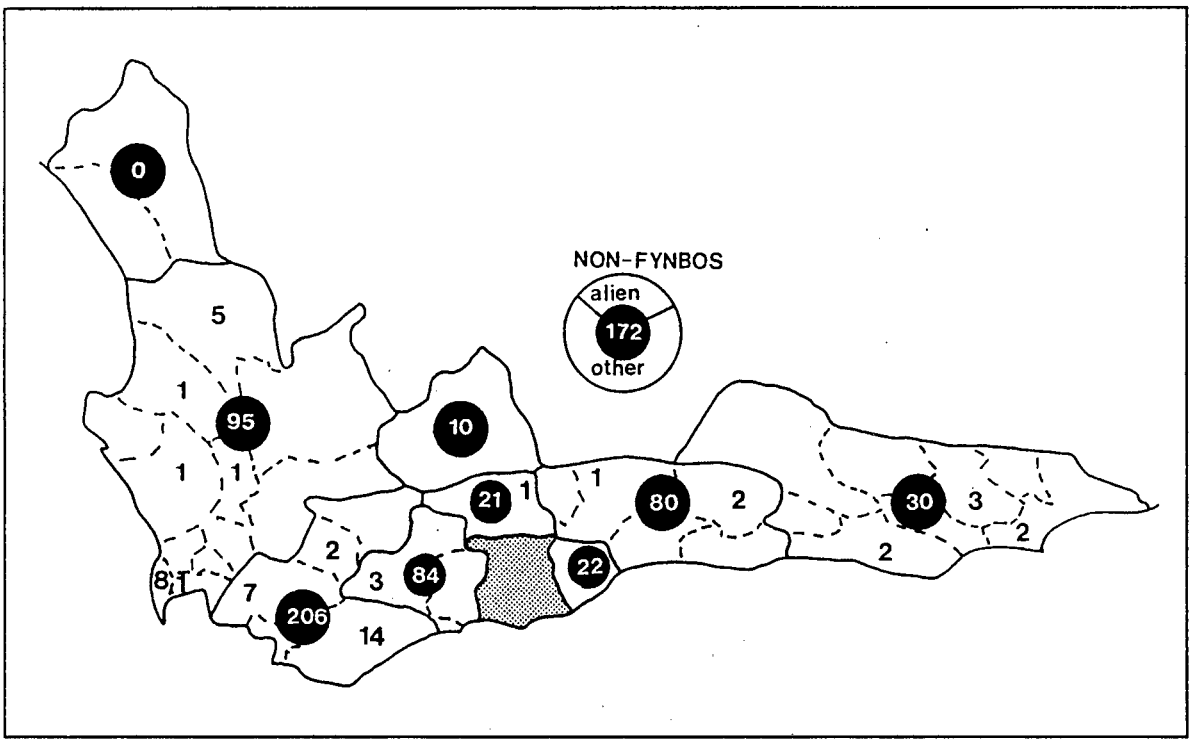

Figure A.2 The distribution of species for which PRECIS and the Catalogue provided conflicting information. White numerals are the total numbers of species listed in PRECIS as occurring in the Riversdale Magisterial District (shaded), positioned in groups (adjacent, intermediate, far: solid lines) of magisterial districts (dashed lines) in which species' distribution ranges most closely occur relative to the Riversdale MD according to the catalogue. Black numerals are the total numbers of species listed in the Catalogue as endemic to specific magisterial districts, but which are recorded from the Riversdale Magisterial District in PRECIS. An additional 11 species could not be delimited to magisterial districts.

Table A.1. An evaluation of the sources of error among Proteaceae species listed as occurring in the Riversdale Magisterial District (MD) in PRECIS and not in the Catalogue

Species	Nearest MD in Catalogue	Nearest MD in latest revision	Source of error
Aulax (Rourke, 1987)			
A. pallasia	Caledon easternmost	Montague (Tradouw Pass) easternmost	PRECIS: ID
Leucadendron (Williams, 1972)			
L. coniferum	Bredasdorp easternmost	Bredasdorp (Elim) easternmost	PRECIS: ID
L. corymbosum•	Worcester closest	Worcester closest	PRECIS: both-single spec.
L. pubibracteolatum•	George westernmost	George (eastern extreme) westernmost	PRECIS: ID
L. uliginosum	Mossel Bay westernmost	Mossel Bay (Cloetes Pass) westernmost	PRECIS: ID
L. xanthoconus	Bredasdorp easternmost	Bredasdorp (Potberg) easternmost	PRECIS: both-separate spec.
Leucospermum (Rourke, 1972)			
L. hypophyllocarp.	Bredasdorp easternmost	Bredasdorp easternmost	PRECIS: loc
L. gracile•	Caledon, Bredasdorp	Bredasdorp easternmost	PRECIS: ID
L. parile	Malmesbury only	Malmesbury only	PRECIS: ID
L. prostratum	Bredasdorp easternmost	Bredasdorp (Brdsdrp Mnts) easternmost	PRECIS: loc
L. truncatulum	Bredasdorp easternmost	Bredasdorp (Brdsdrp Mnts) easternmost	PRECIS: loc
L. truncatum	Swellendam easternmost	Riversdale (at Vermaaklikheid)	Catalogue: error
L. wittebergense	Witteberg & Swartberg Mtn	Also Outeniqua and Warmwaterberg	Uncertain: range extension?
Mimetes (Rourke, 1984)			
M. fimbriifolius	Peninsula only	Peninsula only	PRECIS: ID
Paranomus (Levyns, 1970)			
P. bolusii	Caledon only	Caledon only (Rvrsndrnd Mnts easternmost)	PRECIS: ID
P. bracteolaris	Ceres easternmost	Ceres (Koue Bokkeveld) easternmost	PRECIS: ID
Protea (Rourke, 1982)			
P. amplexicaulis	Caledon easternmost	Montague (Koo) easternmost	PRECIS: ? loc
P. dracomontana	Not in CFR	Drakensberg	PRECIS: ID
P. humiflora	Swellendam easternmost	Swellendam (Lemoenshoek) easternmost	PRECIS: ID
P. mundii	George closest	George closest	Uncertain: range extension?
Serruria (Hutchinson, Phillips & Stapf, 1912)			
S. acrocarpa	Swellendam easternmost	Riversdale (Garcia's Pass)	Catalogue: range extension
S. heterophylla	Kleinmond to Hermanus	Hermanus easternmost	PRECIS: ID
S. elongata	Caledon easternmost	Bredasdorp (Elim) easternmost	PRECIS: loc
S. foeniculaceae	Not listed (= *S. aemula*?)	Cape Flats only	PRECIS: ID
S. nervosa	Bredasdorp only	Bredasdorp only (Brdsdrp Mnts eastermost)	PRECIS: loc
Sorocephalus (Rourke, 1969)			
S. lanatus	Worcester easternmost	Worcester (Hex River Mtns) easternmost	PRECIS: ID

1 ID = identification error or species number miscode;
loc = locality miscode;
both = ID and loc (spec. = specimen)
• These species were added to PRECIS between compiling the checklist (1989) and undertaking the analysis (1990).

listed as endemic to distant magisterial districts by the Catalogue, are recorded from Riversdale in PRECIS: in all cases the Catalogue is correct.

It appears that incorrect identifications make up the bulk (64%) of the PRECIS errors on a species basis, with incorrect locality coding occurring only half as frequently. In 10 percent of the species both errors occurred, either as errors involving separate specimens or together for a single specimen.

In terms of specimens there were a total of 156 specimens with 16 (10%) incorrect localities and 22 (14%) identification errors.

Discussion

Our aim was to evaluate the efficiency of the available data bases with regard to conservation planning in the CFR. We did not attempt a comprehensive evaluation of the data bases. Our results are therefore probably not valid for some areas outside the CFR, or for non-CFR taxa. Given that these data bases were established without conservation requirements as a primary goal, how well do they perform as tools for conservation planning in the CFR?

Although checklists of plant species exist for 205 out of 582 publicly owned nature reserves in South Africa, only 52 (9%) of these may be regarded as comprehensive (Siegfried, 1989).

Published checklists, irrespective of their completeness, are available for only 37 (6%) nature reserves. Since the preservation of species is ostensibly a primary objective in the management of these reserves, comprehensive lists should have been made before management programmes for reserves were drawn up (Siegfried, loc cit).

Outside the existing nature reserves no adequate data base is available for determining areas of conservation worthiness. Although the Catalogue (with a 7 per cent error) performs far better than PRECIS (with a 26-33 per cent error), there appears to be no shortcut to obtaining species lists for any region: detailed surveys of the entire region will have to be undertaken before conservation decisions can be made. Although the Catalogue and PRECIS may provide a starting point for such a survey, verification of records from PRECIS will require considerable initial checking (some 25 to 30 per cent of the total species list in the Riversdale MD). Whereas, many of these are genuine records and many are possibly only errors in the location codes, two-thirds of these may require taxonomic re-evaluation. Some 25 per cent of Proteaceae specimens in PRECIS have not been assigned to the grid square system (T Arnold, pers. comm.): these specimens may well contribute to improving the list, if localities can be adequately resolved. Thus an additional 25 per cent of specimens will have to be checked for locality data in order to produce a regional species list.

Furthermore, excluding the problems outlined above, PRECIS contains only two-thirds of the taxa which probably occur in Riversdale: therefore field work will have to be undertaken to compile a complete checklist. Since data bases similar to PRECIS do not exist for other herbaria in South Africa, these entire collections will have to be manually checked prior to undertaking field work.

Nor is the Catalogue an ideal data base: first published in 1984, it is not computerized and will require frequent updating to remain useful. Its major drawback lies in its distributional data: only the extreme magisterial districts of the distributional range are given when species occur over a wide area. In addition, magisterial districts are inadequate as they lump species from diverse habitats, phytogeographical districts and biomes, in units of arbitrary aerial extent and spatial configuration. Even the quarter-degree grid system used for the local flora (Edwards & Leistner, 1971) has been queried as far too coarse for the CFR (Rebelo & Siegfried, 1990).

Therefore, we strongly recommend that if the goal of conservation on the subcontinent is to be the preservation of biotic diversity, that inter-compatible computerized data bases should be established for all herbaria as a matter of priority. Furthermore, existing data bases should be thoroughly checked, if they are to remain useful. The Catalogue of species for the CFR should be updated periodically (perhaps every decade), based on new records and taxonomic treatises. Regional declines in distribution ranges should be included so that the Catalogue can also provide an inventory of threatened taxa at the local level.

The urgent conservation requirements of the CFR require that, for the present, the conservation of species diversity should be replaced by an approach based on the conservation of broadly floristic (dominant species) and structurally-defined vegetation types (Cowling *et al.*, 1988; Rebelo *et al.*, in press) and biogeographical regions (Kruger, 1977). The latter merely provides a guide to which areas require greater conservation effort. The delimiting of vegetation types will allow an assessment of which areas contain a greater diversity of vegetation types and where scarcer vegetation types occur. Although these have the advantage of providing a rapid assessment of conservation requirements in a region, on their own they cannot suggest where reserves should be located optimally.

Ideally the location of localized endemics should provide a focus for reserves (Terborgh & Winter, 1983; Rebelo & Siegfried, subm.). PRECIS contains only 55 per cent of the endemics listed in the Catalogue for the Riversdale MD, whereas the latter has an error of about 31 per cent for endemics. Since localized endemics require more effort to locate than more common species, existing herbarium data must remain a primary source of information. The use for conservation planning of herbarium data would be greatly increased if they were inter-compatible with Geographic Information Systems (Scott *et al.*, 1987). This can be achieved only by providing coordinates for the exact locality, with an index of resolution to identify localities which are resolvable only (for example) to magisterial district, at a point scale independent of the grid square coordinates used at present.

Conclusions

If a major goal of conservation in southern Africa is to be the preservation of biotic diversity, then:

(1) The existing herbarium data base (PRECIS) at PRE should be thoroughly verified if it is to be useful in the CFR;

(2) Inter-compatible computerized data bases must be established for all herbaria as a matter of priority;

(3) These data bases must be compatible with the locality coordinate requirements of Geographic Information Systems;

(4) The Catalogue of species for the CFR should be computerized and updated periodically, based on new records and taxonomic treatises;

(5) The Catalogue should also highlight regional declines in distribution ranges so as to provide an inventory of threatened taxa at a regional level.

Acknowledgements

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Appendices

Appendix One.

Existing reserves[1] preserving Fynbos in the Cape Floristic Region.

Phytogeographical zone	Reserve name[2]	Authority[3]	Date[4] established	Area conserved[5] Total	Fynbos[6]	Total Fynbos conserved
The Northwestern Province						
Cedarberg District						221601
	Kouebokkeveld MCA	2	1979	96348	91348	
	Cedarberg WA	2	1971	68278	68278	
	Cedarberg MCA	2	1978	61975	61975	
Great Winterhoek District						162092
	Matroosberg MCA	2	1979	79195	79195	
	Groot Winterhoek MCA	2	1981	50819	50819	
	Groot Winterhoek WA	2	1981	19468	19468	
	Touwsrivier TA	4	1978	14000	10500	
	Patryskloof PNR	-	1982	1637	1600	
	Doringkloof PNR	-	1982	532	500	
	Ceres WFG	3	1964	15	10	
Piketberg District	-					0
Sandveld District						5070
Sandveld Zone	-					0
Bokkeveld Zone						5070
	Oorlogskloof NR	1	1984	5070	5070	
Gifberg Zone	-					0
The Southwestern Province						
Malmesbury District						3409
	Hopefield PNR	-	1982	1887	1800	
	Riverlands NR	1	1985	1297	800	
	Hopefield BR	4	1978	315	315	
	Goodwood MA	4	1978	220	220	
	Wingfield N.C. MA	4	1978	63	220	
	Kalabaskraal NR	3	1966-86	(35.)	(13.)	
	Klipheuwel NHS	-	1987	72	12	
	Cape Flats PNR	-	?	20	12	
	Prt 3 Plattekloof NHS	-	1985	24	10	
	6BKD NHS	-	1986	10	10	
	Rondevlei BS	3	1950	137	5	
	Braken NR	3	1978	36	2	
	Durbanville NR	3	1967	6	2	

Phytogeographical zone	Reserve name[2]	Authority[3]	Date[4] established	Area conserved[5] Total	Fynbos[6]		Total Fynbos conserved
	Zandvlei NR	3	1978	11	1		
Peninsula District							27755
	Cape Peninsula NA	?	1983	16445	11200	ae	
	Cape of Good Hope NR	3	1939	7675	7000		
	Table Mountain NR	3	1964	2904	2000		
	Silvermine NR	3	1965	2150	1998		
	Tokai SF	2	1884	1952	1952		
	Cecelia SF	2	1833	1293	1293		
	Da Gama Park MA	4	1978	909	909		
	Klaver Valley MA	4	1978	716	716		
	Kirstenbosch NBG	5	1913	527	477		
	Silvermine MA	4	1978	210	210		
Riviersonderend District							73157
	Riviersonderend MCA	2	1981	43037	43037		
	Sonderend SF	2	1943	26029	26029		
	Greyton NR	3	1977	2220	2220		
	Jonaskop PNR	-	1979	1871	1871		
Franschoek District							58519
	Hottentots Holland NR	2	1979	23579	23579		
	LaMotte & Grabouw SF	2	1902	11700	11700		
	Hottentots Holland MCA	2	1979	17532	12800	e	
	Jonkershoek SF	2	1933	10210	10210		
	Helderberg NR	3	1962	385	130		
	Assegaaibos NR	1	1960	168	90		
	Jan Marais NR	3	1976	23	10		
DuToitskloof District							122212
	Hawequas MCA	2	1981	87706	87706		
	Kluitjies Kraal MCA	2	1984	28835	28835		
	Mount Rochelle NR	3	1972	1759	1700		
	Elandsberg PNR	-	1973	2600	1500		
	Paarl Mountain NR	3	1977	1910	1200		
	Villiersdorp NR	3	1965	550	530		
	Zewenfontein NR	2	1936	376	376		
	Paardeberg NR	3	1986	3383	365		
Houwhoek District							64416
	Highlands SF	2	1939	36806	36806		
	Kogelberg SF	2	1940	14006	14006		
	Nuweberg SF	2	1902	5890	5890		
	Lebanon SF	2	1911	3476	3476		
	Fernkloof NR	3	1971	1446	1400		
	Paardepoort SF	2		808	808		
	Maanskynkop NR	1	1973	850	790		
	Vogelgat PNR	-	1971	602	600		
	Kleinmond CR	3	1977	367	280		
	Harold Porter NBG	5	1959	191	176		
	Caledon NR	3	1964	214	170		
	Krabbefontein NHS	-	1986	7	7		

Phytogeographical zone	Reserve name[2]	Authority[3]	Date[4] established	Area conserved[5] Total	Fynbos[6]		Total Fynbos conserved
	Rooiels NR	3	1984	4	4		
	Barkai NHS	-	1986	3	3		
Bredasdorp District							17699
	De Hoop NR	1	1956	17846	12286		
	Brandfntn/Rietfntn PNR	-	1969	1200	1134		
	San Sebastian PNR	-	1982	1154	1100		
	Quion Point SF	2	1895	984	800		
	Salmonsdam NR	1	1962	846	700		
	Paapekuilsfontein NHS	-	1986	902	650		
	Waenhuiskrans SF	2		262	230		
	De Mond SF	2	1941	617	220		
	De Mond NR	2	1975	301	205		
	Hagelkraal/Celt Bay SF	2	1895	543	100		
	Bredasdorp NR	3	1964	86	60		
	Walker Bay SF	2	1895	7118	52		
	Heuningnesrivier PNR	-	1982	296	50		
	Brian Mansergh PNR	-	1969	92	50		
	Uilenkraal SF	2	1895	409	40		
	Renosterkop PNR	-	1978	765	22		
Potberg District							2500
	De Hoop NR	1	(-)	(-)	2500		
Mossel Bay District							2705
	Gouriqua NR	3	?	2500	2100	nl	
	Blombosfontein	2		265	265		
	Kleinjongensfontein	2		549	130		
	Pauline Bohnen NR	3	1982	140	130		
	Geelkrans NR	2	1977	165	80		
Coastal Mountain Province							
Koo Langeberg District							59936
	Langeberg West MCA	2	1979	58326	58326		
	Montague MR	3	1972	1200	1200		
	Dassieshoek NR	3	1977	865	400		
	Romansrivier NR	1	1977	30	10		
Langeberg District							85023
	Langeberg East MCA	2	1981	40391	40391		
	Grootvadersbos Garcia SF	2	1897	18501	18501		
	Boosmansbos WA	2	1978	14200	14150		
	Marloth NR	2	1981	11269	11260		
	Swellendam SF	2	1927	721	721		
Outeniqua District							156043
	Langkloof SF	2	1923	26758	26758	f	
	Ruitersbos SF	2	1936	17862	17862	f	
	Witfontein SF	2	1896	15219	15219	f	
	Karatara SF	2	1923	12070	12070	f	
	Stormberg River SF	2	1925	10381	10381	f	
	Attaqwaskloof NR	2	1986	9880	9880	f	

Phytogeographical zone	Reserve name[2]	Authority[3]	Date[4] established	Area conserved[5] Total	Fynbos[6]		Total Fynbos conserved
	Moordkuil Mountains NR	2		8270	8270		
	Kruisfontein SF	2	1906	7387	7387	f	
	Goudveld SF	2	1915	7099	7099	f	
	Bergplass SF	2	1922	6836	6836	f	
	Church Millwood NR	2	1987	6032	6032	f	
	Jonkersberg SF	2	1911	5329	5329	f	
	Kransbos SF	2	1922	4999	4999	f	
	Buffelsnek SF	2	1896	3491	3491	f	
	Gouna SF	2	1918	3200	3200	f	
	Whiskey Creek NR	2	1984	2716	2716	f	
	Tsitsikamma Coast NP	6	1964	2840	1840		
	Goukamma NR	1	1960	2270	1780		
	The Lakes NP	6		2100	1200		
	Lily Vlei NR	2	1986	1083	1083		
	Keurbooms SF	2	1925	2717	1032		
	Ysternek NR	2	1972	1212	500		
	Sinclair NR	2	1982	1828	298		
	The Lakes NCS	1	1969	430	204		
	Robberg NR	1	1945	175	150		
	Bosbok PNR	-		103	103		
	Keurbooms River NR	1	1969	760	90		
	Ebb & Flow NR	3	1961	125	90		
	Plettenberg Bay Club	-	1980	67	67		
	Kanon PNR	-	1971	43	43		
	Skuilte PNR	-	1981	15	15		
	Samland PNR	-	1973	10	10		
	Van Kerwel NR	3	1968	9	9		
Kouga District							178213
	Baviaanskloof SF	2	1923	68532	68532	f	
	Formosa SF	2	1923	51096	51096	f	
	Tsitsikamma SF	2	1890	15651	15651	f	
	Lottering SF	2	1923	14368	14368	f	
	Bloukrans SF	2	1925	9305	9305	f	
	Blueliliesbush SF	2	1925	9172	9172	f	
	Witelsbos SF	2	1925	7990	7990	f	
	Krom River SF	2	1930	1652	1571		
	Rebelsrus PNR	-	1974	394	250		
	Tsitsikamma Forest NP	6	1964	3011	150		
	Seekoei River NR	1	1969	141	36		
	Noorsekloof	3	1983	28	28		
	Anne Robinson PNR	-	1980	30	15		
	Yellowwoods NR	3	1982	30	15		
	Cape St Francis NR	1	1977	36	30		
	Linton-Grange WFR	3		21	2		
	Linkside NR	3		17	1		
	Kabega Park WFR	3		10	0.5		
Southeastern Province							
Cockscomb District							150288
	Cockscomb SF	2	1927	54277	54277	f	
	Groendal WA (priv)	2	1976	31172	31172	f	

Phytogeographical zone	Reserve name[2]	Authority[3]	Date[4] established	Area conserved[5] Total	Fynbos[6]		Total Fynbos conserved
	Otterford SF	2	1896	18033	18033	f	
	Woody Cape NR	3	1985	15460	15460	f	
	Groendal WA(state)	2	1976	25044	13446		
	Suurberg SF	2	1985	21121	6700		
	Longmore SF	2	1896	4777	4777	f	
	Bosch Hoek NR	3	1985	1600	1600	f	
	Alexandria CR	2	1986	15813	1000		
	Boxwood NR	3	1985	881	881	f	
	Grahamstown TA	6	1978	6200	875		
	Congas Kraal NR	3	1985	601	601	f	
	Loerie NR	3	1982	756	459		
	Beggars Bush SF	2		276	276		
	Thomas Bains NR	1	1980	975	150		
	Cape Recife NR	3	1973	336	150		
	Cycad NR	1	1973	189	120		
	Van Stadens River WFR	3	1960	286	80		
	Sylvic NR	3	1979	78	78		
	Grahamstown NR	3		76	76		
	Sardinia Bay NR	3	1980	320	56		
	1820 Settlers WFG	1	1965	61	20		
	Settlers Park NR	3	1938	54	0.5		
Inland Mountain Province							
Swartberg District							
Swartberg Zone							121600
	Swartberg SF	2	1912	109021	105000	e	
	Swartberg East MCA	2	1978	11606	9300	e	
	Groot Swartberg MCA	2	1978	10386	7000	e	
	Nietgenaamd NR	1	1978	1577	300		
KleinSwartberg Zone							57000
	Towerkop SF	2	1912	33541	31000	e	
	KleinSwartberg MCA	2	1978	29678	22000	ae	
	Gamkapoort NR	1	1980	8002	?		
	Buffelspoort NHS	-	1987	4083	4000	e	
Karoo Island Zone							55250
	Kammanasie MCA	2	1978	23433	23433		
	Anysberg MCA	2	1978	28966	13000	e	
	Rooiberg MCA	2	1978	12417	12417		
	Gamka MR	1	1970	9420	6400		
Witteberg District	-						0

1 Considerable discrepencies exist between published and unpublished data. For land transferred from the Department of Environment Affairs (Forestry Branch) to the Chief Directorate of Nature and Environmental Conservation (over which considerable confusion reigns) Cowan (1987) was used to determine privately owned MCA's, from which State Forest was determined from Siegfried (1989).
For all publically-owned conservation areas Siegfried (1989), based on data collected by correspondence with the conservation authorities, was used.
Jarman (1986) was used for Private Nature Reserves and National Heritage Sites.

2
BR Bombing Range (Military NR);
BS Bird Sanctuary;
CR Coastal Reserve;
MA Military Area;
MCA Mountain Catchment Area (private land managed under the Mountain Catchment Act);
MR Mountain Reserve;
NA Nature Area;
NBG National Botanic Garden;
NCS Nature Conservation Station;
NHS National Heritage Site;
NP National Park;
NR Nature Reserve;
PNR Private Nature Reserve;
SF State Forest (figures include afforested land and State-owned MCA);
TA Training Area (Military NR);
WA Wilderness Area;
WFG Wild Flower Garden;
WFR Wild Flower Reserve.

3
1 Chief Directorate of Nature and Environment Conservation (CDNEC);
2 Department of Environment Affairs; Management and control of all non-SF areas were passed to CDNEC in 1986;
3 CDNEC sponsored reserves;
4 South African Defence Force;
5 National Botanic Gardens;
6 National Parks Board.
NHS and PNR are administered by the landowner.

4 For MCA the date of proclaimation is given. Data from Siegfried (1989) and Cohen (1987)

5 Values include South Coast Strandveld, the early seral stages of which comprise Dune Fynbos, and include Afromontane vegetation and afforested areas on State Forest (for which no figures are available). Jarman (1986) was regarded as definitive for the area covered by Fynbos vegetation.

6 The following adjustments to Siegfried (1989) data base were made:
a MCAs and NAs which apparently included NHS, NR and PNR. The areas of the latter removed from the total.
f SF where Afromontain forest might comprise a fair proportion of the area.
e conservation areas for which no data on the area of Fynbos vegetation currently exist. Data are corrected for the maximum area of Fynbos in the region recorded by Moll & Bossi (1984).
nl conservation areas not listed in any of the three lists.

Appendix Two

Proposed reserves which would preserve Fynbos vegetation.

Phytogeographical zone	Reserve name	Area proposed for conservation (ha) Total	Fynbos	No of rares recorded[1]	Priority ranking[2] (ha)	Total area proposed
TOTAL CONSERVED:						416045
The Northwestern Province						
Cedarberg District					0	
Great Winterhoek District						1750
	Ceres Valley/Gydo Pass	3500	1750		E13	
Piketberg District						23200
	Picketberg Mountain	22000	22000		A39	
	Picketberg East Foothills	2400	1200		A41	
Sandveld District						
Sandveld Zone						27500
	Verlorenvlei Coastal Lake	38000	26000		A2	
	Olifantsberg	2000	1500		A46	
Bokkeveld Zone						0
Gifberg Zone						0
The Southwestern Province						
Malmesbury District						57339
	Hopefield Sandveld	40000	34635		A6.3	
	Langebaan Bokpunt Park	50650	15625		A6.1	
	Bokbaai	4800	3200		A6.2	
	Mamreweg	2350	1600		A29	
	Klein Dassenberg	1500	750		A26.1	
	Zeekoeivlei Coastal Park	1600	264		A9	
	Mamre/Pella & Dassenberg	3601	250		A26.3	
	Pella Rearch Site	269	250	8 (2,0,3)	A26.4	
	Vlakfontein	280	230	12 (5,1,1)	A24	
	Klipfontein	170	100	5 (0,0,0)	A32	
	Kraaifontein FR	150	140	5 (3,1,1)	A15	
	Blouberg Koppie	600	100	4 (3,0,0)	A22	
	Malmesbury SE Commonage	240	100	7 (0,0,0)	A31	
	Kuilenberg Koppie	100	40	3 (1,0,0)	A21	
	De la Gift	50	40	1 (1,0,0)	A49	
	Eensaamheid Extension	22	10	8 (1,0,0)	A20	
	Groenrivier	60	5	8 (4,0,1)	A50	

Phytogeographical zone	Reserve name	Area proposed for conservation (ha) Total	Fynbos	No of rares recorded[1]	Priority ranking[2]	Total area proposed (ha)
Peninsula District						0
Riviersonderend District						0
Franschoek District						1100
	Franshoek Pass	1800	1100		B1	
DuToitskloof District						16300
	Paardeberg	4000	3800		A23	
	Saron	4000	2100		A38	
	Simonsberg	2000	1800		A53	
	Groenberg	2800	2400		A27	
	Paarl Mountain	1900	1350		A19	
	Riebeck Kasteel Mountain	1800	1200		A34	
	Brandvlei Extension	3500	1000		E3	
	Brandvlei Valley	3000	1000		E4	
	Voelvlei	870	850	13 (5,0,0)	A33	
	Languedoc	700	700	2 (1,1,0)	A44	
	Wemmerhoeksvlei	120	100	3 (1,2,0)	A43	
Houwhoek District						41325
	Babylonstoring-Steenboksberg		25000	25000		B18.1
	Caledon Swartberg	7000	6500		B5	
	Kleinrivier Mountains	5000	5000		B18.2	
	Rooiels Nature Area	4750	4000		B15	
	Simonskop	3450	450		B4	
	Sir Lowries Pass	375	375	4 (0,0,0)	A52	
Bredasdorp District						68450
	Overberg Armament Range	42000	35000		B29	
	Soetanysberg Nature Area	40000	21000		B23	
	Elim/Viljoenshof	5000	4500		B24	
	Soetmuisberg-Die Poort	4000	2700		B18.3	
	Elim Hills	2000	2000		B25	
	Zandvlakte/Heuningrug	1850	1850		B26	
	Awila	1600	1400		B22	
Potberg District						500
	Diepkloof	2000	500		B30	
Mossel Bay District						6800
	Puntjie	8000	6800		B31	
Coastal Mountain Province						
Koo Langeberg District						0
Langeberg District						10950
	Corente River Hill	8000	7000		B14	
	Cloete's Pass	5000	2000		C19	
	Bromberg/Hassekwaskloof	2200	1800		B7	
	Voorhuis	2600	150		E9	

Phytogeographical zone	Reserve name	Area proposed for conservation (ha) Total	Fynbos	No of rares recorded[1]	Priority ranking[2]	Total area proposed (ha)
Outeniqua District						19001
	Doringrivier NR	8660	7700		C15	
	Millwood	5500	5300		C12	
	Perdepoort	1500	1500		C17	
	Brandwag	1500	1170		C8	
	Goukamma extension	1600	1000		C6	
	Keytersnek	1200	900		C11	
	Petrus Brand NR	1893	601		C4	
	Sandkraal	1310	830		C9	
Kouga District						36632
	Stormsrivier	13500	13300		C1	
	Langkloof Area	15000	12000		D9	
	Churchill Dam	4800	4300		D5	
	Oyster Bay Dune Coast	30000	4000		D1	
	Tsitsikamma Flats	5000	2000		D3	
	Keurboomsrivier NR	2717	1032		C5	
Southeastern Province						
Cockscomb District						105250
	Grahamstown Heights	80000	70000		D16	
	Elands River Valley	10000	8000		D11	
	Hankey Loerie	9500	8000		D10	
	Salem	7500	7000		D18	
	Papiesfontein/Heather Cliff	10000	5000		D2	
	Swartwatersberg	4000	4000		D17	
	Posfontein	2000	2000		D12	
	Heather Glen	1250	1250		D15	
Inland Mountain Province						
Swartberg District						
Swartberg Zone						0
KleinSwartberg Zone						0
Karoo Island Zone						0
Witteberg District						0

1 The total number of Red Data Book species is followed, in parenthesis, by the total Red Data Book Proteaceae, Ericaceae and Restionaceae.

2 Priority rankings are quoted for the five regions (A-E) presented in Jarman (1986). No ranking of proposed reserves between the five regions has been published.

Appendix Three

Proteaceae distributional data base

Section one: list of species

Generic and species names are abbreviated to a two letter and four letter code, respectively. This code will be used for the Protea Atlas Project. These codes comprise the first letters in each case (but Ls and Ld for *Leucospermum* and *Leucadendron* respectively). Species names with conflicting codes use the first letter and last three consonents. Nomenclature follows Bond and Goldblatt (1984).

001 MI CUCU
002 MI FIMB
003 MI SAXA
004 MI SPLE
005 MI ARGE
006 MI ARBO
007 MI HOTT
008 MI STOK
009 MI HIRT
010 MI PAUC
011 MI PALU
012 MI CAPI
013 OR ZEYH
014 DI PARI
015 DI MYRT
016 DI DIVA D
017 DI DIVA M
018 DI FRAT
019 DI THYM T
020 DI THYM M
021 DI PROT
022 DI BUEK
023 SO PINI
024 SO ALOP
025 SO CLAV
026 SO PALU
027 SO CRAS
028 SO TERE
029 SO IMBR
030 SO CAPI
031 SO SCAB
032 SO LANA
033 SO TENU
034 SP TULB
035 SP CAUD
036 SP CONF
037 SP THYR
038 SP INCU
039 SP ARGE
040 SP PROP
041 SP SALS
042 SP SETA
043 SP NUBI
044 SP PARI
045 SP BARB
046 SP COLO
047 SP PROL
048 SP SQUA
049 SP ERIC
050 SP LONG
051 SP CURV
052 SP RACE
053 SP MOLL
054 LS SAXO
055 LS CUNE
056 LS INNO
057 LS GERR
058 LS CONO C
059 LS CONO V
060 LS GLAB
061 LS PLUR
062 LS PRCX
063 LS FULG
064 LS TRCTM
065 LS MUIR
066 LS ERUB
067 LS UTRI
068 LS SPAT
069 LS PROF
070 LS VEST
071 LS TOTT
072 LS LINE
073 LS CFLM
074 LS PATE
075 LS CDTM
076 LS FORM
077 LS CATH
078 LS GRAN
079 LS GUEI
080 LS PRSM
081 LS REFL
082 LS HYPO H
083 LS HYPO C
084 LS TOME
085 LS RODO
086 LS PARI
087 LS AREN
088 LS CALL
089 LS WITT
090 LS ROYE
091 LS HETE
092 LS TTLM
093 LS BOLU
094 LS PROS
095 LS PEDU
096 LS SECU
097 LS OLEI
098 LS MUND
099 LS GRAC
100 LS SAXA
101 LS HAMA
102 LS WINT
103 VE ALPI
104 VE AMOE
105 VE LATE
106 VE OBTU O
107 VE OBTU A
108 PR CAFF
109 PR SIMP
110 PR PARV
111 PR DRAC
112 PR NUBI
113 PR NITI
114 PR INOP
115 PR GLAB
116 PR RUPI
117 PR RUBR
118 PR CPTN
119 PR CURV
120 PR LAET
121 PR WELW
122 PR GAGU
123 PR EROI
124 PR SRFL
125 PR SSCL
126 PR CRYO
127 PR PRUI
128 PR REPE
129 PR ARIS
130 PR LANC
131 PR ROUP R
132 PR ROUP H
133 PR EXIM
134 PR CPCT
135 PR OBTU
136 PR SUSA
137 PR BURC
138 PR LONG
139 PR PUDE
140 PR LORI
141 PR NERI
142 PR LAUR
143 PR LEPI
144 PR CORO
145 PR SPEC
146 PR STOK
147 PR GRAN
148 PR MAGN
149 PR HOLO
150 PR CAES
151 PR SCOR
152 PR LORE
153 PR ASPE
154 PR SCBR
155 PR DENT
156 PR PISC
157 PR REST
158 PR SUBV
159 PR LACT
160 PR PUNC
161 PR MUND
162 PR AURE A
163 PR AURE P
164 PR VENU
165 PR FOLI
166 PR TENA
167 PR VOGT
168 PR INTO
169 PR MONT
170 PR ACAU
171 PR ANGU
172 PR LAEV
173 PR CONV
174 PR REVO
175 PR RECO
176 PR EFFU
177 PR SULP
178 PR NAMA
179 PR PEND
180 PR AMPL
181 PR CORD
182 PR DECU
183 PR SUBU
184 PR HUMI
185 PR SPHL
186 PR ACUM
187 PR CANA
188 PR NANA
189 PR WITZ
190 PR PITY
191 PR MUCR
192 PR ODOR
193 LD CORI
194 LD BRUN B
195 LD BRUN F
196 LD SLRE

197 LD THYM
198 LD LEVI
199 LD CINE
200 LD LINI
201 LD GALP
202 LD DUBI
203 LD CONC
204 LD REMO
205 LD PUBE
206 LD BONU
207 LD ARCU
208 LD SERI
209 LD NITI
210 LD ERIC
211 LD SING
212 LD SORO
213 LD NERV
214 LD DREG
215 LD ALBU
216 LD RUBR
217 LD ARGE
218 LD VERT
219 LD CORY
220 LD LAXU
221 LD SHEI
222 LD MEYE
223 LD GLAB
224 LD OLEN
225 LD LORA
226 LD ROOD
227 LD CADE
228 LD GYDO
229 LD SESS
230 LD DAPH
231 LD BARK
232 LD BURC
233 LD TRAD
234 LD ORIE
235 LD PUBI
236 LD TINC

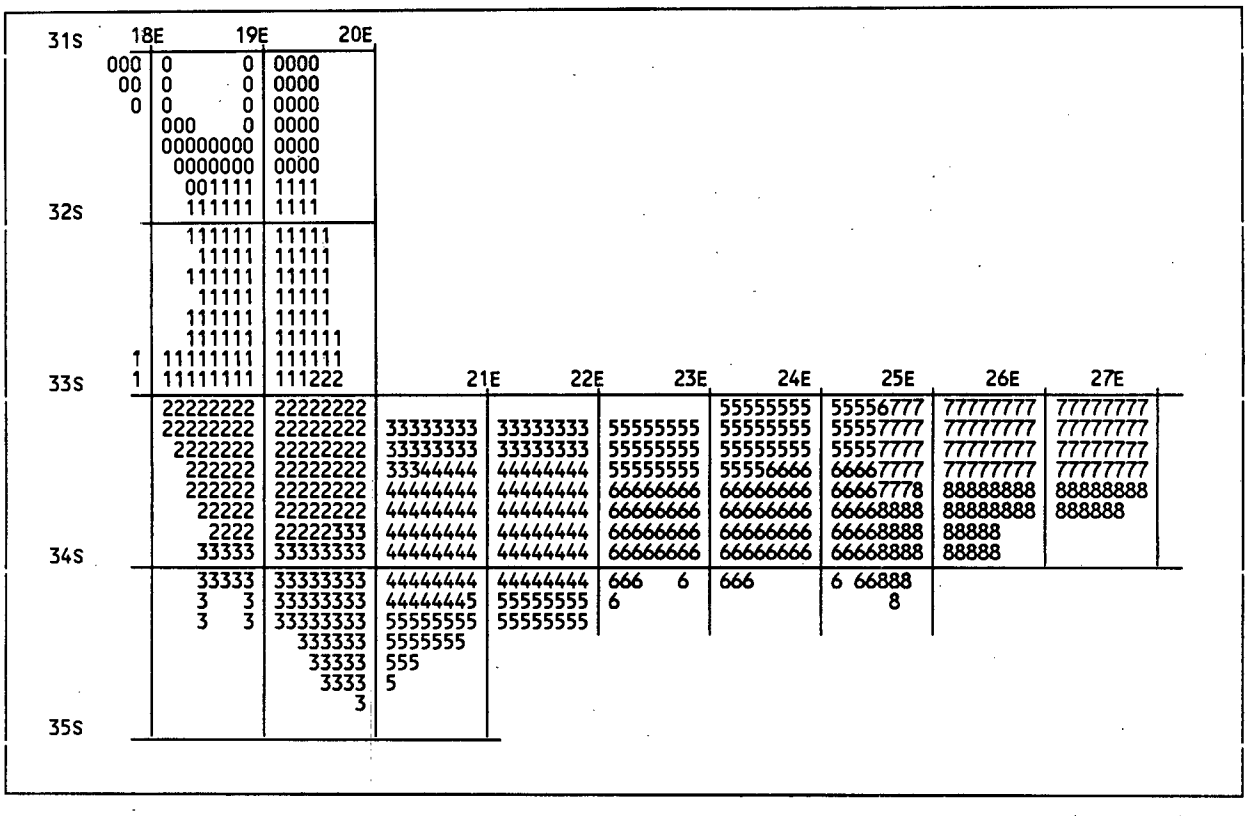
237 LD CORD
238 -- ----
239 LD GLOB
240 LD ELIM E
241 LD ELIM S
242 LD ELIM V
243 LD CHAM
244 LD FLOR
245 LD ULIG U
246 LD ULIG G
247 LD LOER
248 LD RADI
249 LD ROUR
250 LD CNCM
251 LD SFLM
252 LD MACO
253 LD MICR
254 LD XANT
255 LD LANI
256 -- ----
257 LD MODE
258 LD SLLG
259 LD DIEM
260 LD FLEX
261 LD SLGM
262 LD FOED
263 LD PROC
264 LD DISC
265 LD CRYP
266 LD EUCA
267 LD MERI
268 LD CFRM
269 LD GAND
270 LD LAUR
271 LD STRO
272 LD SPIS S
273 LD SPIS F
274 LD SPIS P
275 LD SPIS N
276 LD SPIS O

277 LD TERE
278 LD SPIR
279 LD NOBI
280 LD MUIR
281 LD COMO
282 -- ----
283 LD PLAT
284 AU PALL
285 AU CANC
286 AU UMBE
287 PA SPIC
288 PA BOLU
289 PA CAND
290 PA TOME
291 PA BRAC
292 PA LAGO
293 PA CAPI
294 PA ABRO
295 PA DISP
296 PA DREG
297 PA ESTE
298 PA CENT
299 PA SPAT
300 PA ROOD
301 PA ADIA
302 PA SCEP
303 PA REFL
304 PA LONG
305 SE ACRO
306 SE ADSC
307 SE AEMU
308 SE AITO
309 SE BROW
310 SE CAND
311 SE COLL
312 SE CONF
313 SE CYAN
314 SE CYGN
315 SE DECI
316 SE DECU

317 SE DODI
318 SE ELON
319 SE FASC
320 SE FLAG
321 SE FLAV
322 SE FLOR
323 SE FUCI
324 SE FURC
325 SE GLOM
326 SE HETE
327 SE HIRS
328 SE INCO
329 SE INCR
330 SE KRAU
331 SE LEIP
332 SE LINE
333 SE MEIS
334 SE MILL
335 SE NERV
336 SE PEDU
337 SE PINN
338 SE PHYL
339 SE ROSE
340 SE ROST
341 SE ROXB
342 SE RUBR
343 SE TRIL
344 SE TRIT
345 SE VILL
346 SE WILL
347 SE ZEYH
348 SE ONDE
349 SE GLAB
350 SE AMOE
351 SE PATE
352 BR STEL
353 FA GALP
354 FA SALI
355 FA MCNA
356 FA SPEC

Appendix Three

Section two: map of grid showing location of grid squares.



Numbers assigned to the eighth-degree grid squares used in the study.

Numbering is from left to right in blocks bordered by 20E, 22E and 24.5E.
Extreme northern and eastern grid squares are not included. Shown sequence starts at grid square number 43 in the extreme north west.
The Kamiesberg (not shown) occupies grid squares 13, 14, 18 and 19.

Appendix Three

Section three: list of grid squares occupied by each species.

Format: i3,i2,9(i3,i2).
Key: species-number, line-no-for-species,
9 X (site-number, total-herbarium-specimens)

```
  1 1197 2212 2243 2244 2258 1283 1284 1288 1297 1
  1 2303 3307 2309 1312 1349 4352 1355 1356 1472 1
  1 3316 1320 2321 1325 1328 1332 1334 1339 1340 4
  1 4358 1362 1364 1391 1424 1440 1445 2463 1464 1
  1 5466 2467 2470 2329 1330 1341 1342 1648 1668 3
  1 6474 1476 1513 1529 1530 1532 1645 1670 1671 1
  2 1303 7316 5329 7339 3
  3 1358 1359 1360 5361 1362 4532 2364 5
  4 1464 3467 3468 2469 1470 1472 1488 1654 1655 1
  4 2694 1671 2672 1677 1682 1
  5 1308 2309 2310 1320 6321 7324 1325 1327 2328 2
  6 1330 7340 8
  7 133016340 1
  8 1341 5
  9 1303 2316 1339 7340 7341 3349 3357 2358 1329 1
 10 1654 4655 2668 2670 2671 4672 1674 2677 2676 2
 10 2660 2661 2680 1681 4682 1683 1
 11 1349 9350 6
 12 1330 4331 1332 6340 4341 2349 3
 13 1330 1340 3341 1349 1
 14 1227 2242 1257 3271 2284 2285 2
 15 1227 3242 4256 1
 16 1316 2329 7339 7
 17 1295 1296 1309 2310 1320 2321 5322 1331 1332 8
 17 2341 1342 3349 1
 18 1330 1340 7341 6342 1
 19 1330 8331 3
 20 134012
 21 1252 1253 1266 2267 1278 1281 1282 3292 2293 1
 21 2318 1303 6304 1305 4316 5279 1280 1
 22 1295 2307 1308 4
 23 1327 3328 3338 2
 24 1324 3
 25 1307 1308 1320 8321 3340 3341 6349 1350 1
 26 1330 2
 27 1312 1325 4
 28 1283 2284 2296 5
 29 1179 1180 1194 1227 4242 7256 3257 1
 30 1164 1165 6179 2180 5198 4212 1213 1228 1
 31 1197 2211 2212 2228 2
 32 1146 4156 2157 4167 116810169 3212 4213 3214 1
 32 2147 1244 4247 2258 5259 8261 8260 2228 6229 8
 32 3230 3231 2
 33 1330 2331 2
 34 1228 5229 8
 35 1124 1133 1136 1145 2146 1156 3157 3167 2168 5
 35 2198 1199 2200 1212 2213 4214 1228 1229 5230 3
 35 3231 1243 1247 2248 1169 1183 4184 2186 1
 36 1 91 1101 1124 2135 2136 5146 2157 1169 1231 1
 36 2273 2274 1283 1284 2296 2297 2309 1310 3311 2
 36 3386 5407 4408 4572 1573 1396 1548 1549 1568 6
 36 4635 2592 1246 1247 5260 2261 4312 2320 3321 1
 36 5569 2591 1593 2615 2385 1
 37 1284 2296 3310 1334 1335 1
 38 1114 4124 6135 4136 8145 3146 7156 1157 4158 1
 38 2183 1211 1212 2213 1227 3228 3229 3246 1247 1
 38 3284 4309 1310 1167 3168 4169 2170 1258 4259 2
 38 4261 6275 1
 39 1311 4312 6
 40 1284 1295 1307 1308 2321 1328 5338 1
 41 1296 1297 4
 42 1283 1284 1296 3309 1320 7321 9330 3340 1341 1
 43 1468 5
 44 1307 1320 1321 1324 1325 1326 4327 1328 246410
 44 2465 1466 1469 1467 7468 347012
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214 1406 2407 1408 356815569 4570 4592 4593 3 246 1625 1626 1637 1642 1643 3644 2661 2662 4660 5
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216 3243 5242 2244 7246 2247 1248 3249 2258 6260 2 250 3654 1648 4658 2659 1685 2686 2695 2
216 4274 2257 128212284 1285 3283 2286 2297 129411 251 1352 1353 1355 1332 2321 6340 6330 2341 2323 1
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219 1282 5244 1252 3251 1256 225711270 1271 4272 2 254 4360 1361 1529 5
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285 4669 1622 1
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286 2354 1355 1356 1357 1358 1360 1359 1361 1362 2
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351 1330 3331 2340 2341 3
352 1323 1308 1309 1332 1340 1258 1470 1472 1486 1
352 2147 1157 1158 2310 1320 1316 1321 2282 1294 1
352 3260 1261 1274 1319 1480 1
353 185916860 1862 1
354 185915860 586213858 3
355 1676 9672 2692 6
355 2859 1860 1
356 185923860 886210867 2
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New species described during 1989 and 1990, and therefore not included in the analyses:

Mi chry:
--- 1443 3

Se effu:
--- 1101 1108 1111 1121 1124 1122 2133 3132 1143 1
--- 2145 1155 3156 3157 1167 1168 1182 1

Both species were included in Paper 2.2.

Mi chry was included in Paper 3.1
Mi chry was omitted from Paper 3.2, which therefore requires a single additional reserve to be unconditionally added at grid square 443, with no other changes.

Se effu does not affect the results as it was considered part of Se cyne, with which it has an extensively overlapping distribution.

Appendix Four.

Rarity Status within the Proteaceae

Categorization of Proteaceae species into Rabinowitz forms of rarity and Red Data Book Status, including annotations of selected unusual entries. Numerical codes are given in Appendix Three.

1. Common species (Rabinowitch: Widespread, Broad, Dense)

not threatened:

Mimetes 1;
Spatalla 37, 45;
Leucospermum 55, 59, 80, 85, 88, 89, 90, 97;
Protea 113, 123, 124, 128, 133, 134, 137, 138, 140, 141, 142, 143, 144, 147, 148, 153, 154, 156, 159, 160, 161, 165, 166, 168, 170, 172, 174, 176, 177, 180, 181, 183, 185, 186, 187;
Leucadendron 200, 205, 215, 216, 225, 229, 251, 254, 255, 261, 266, 269, 270, 277;
Aulax 286;
Serruria 305, 315, 319, 323, 335, *effu.*

no longer threatened:

Protea convexa (173): (1982-5: r) Since discovered on two additional mountain ranges.
Leucadendron ericifolium (210): (1985: v, 1982: e) Now known from many localities over a 100 km-long area.
L. modestum (257): (1982-5: v) Known from 11 populations over a 120 km-long range. Threats: grazing, burning, alien invasion and cultivation, but currently under little pressure.
L. nobile (279): (1985: r, 1982: n) Probably more common than appreciated previously. No threats.

rare:

Serruria candicans (310): (1985: r, 1982: v) Known from three disjunct localities.

vulnerable:

Leucospermum grandiflorum (78): (1982-5: n) Known from five isolated localities over a 60 km range. Agricultural expansion threatens most extant populations.
Protea lanceolata (130): No change in status: Occurs on 160 km-long area near coast in ecotonal areas (usually alkaline-neutral sands adjacent thicket vegetation, but easternmost populations occur on gravelly soils) in demand for cash-crop agriculture and susceptable to alien invasion.
Leucadendron corymbosum (219): No change in status. Known from 15 localities on potentially arable land: extinct at two locations. Threats: agriculture.
L. platyspermum (283): No change in status: A vigorous plant occurring in many large populations over an 85 km range. The picking of infructescences (for dried cones and seeds for cutivation) has reduced numbers of female plants in many populations, although currently the cut flower trade is marketing male foliage.
Paranomus abrotanifolius (294): (1985: r, 1982: n) Known from two localities separated by 70 km. Threats: agriculture.

endangered:

Leucadendron coriaceum (193): (1982-5: r) A species with the same distribution pattern and habitat requirements as *Protea decurrens*, but known from only three localities. The westernmost populations are apparently extinct. Threats: agriculture and too-frequent burning.

2. Truly sparse species (Widespread, Broad, Sparse)

not threatened:

Leucospermum 71, 94;
Protea 145;
Leucadendron 196, 272, 273, 274;
Aulax 284;
Paranomus 288.

no longer threatened:

Serruria inconspicua (328): (1985: r, 1982: n).

vulnerable:

Protea scorzonerifolia (151): (1982-5: n) Heavy impacts by urbanization and agriculture have eliminated many populations. A lowlands species occurring predominantly in prime agricultural and urban areas.

Serruria incrassata (329): (1982-5: i) Known from three localities in 20 km-long area. Threats: alien infestation, ploughing.

endangered:

Serruria brownii (309): (1985:v, 1982: r) Five populations known from two areas about 45 km apart. Threats: ploughing, alien plants and grazing.

3. Common species with classic restricted habitat (Widespread, Restricted, Dense)

not threatened:

Sorocephalus 25, 32;
Spatalla 35, 38, 44, 51, 52;
Leucospermum 64, 67, 68, 70, 72, 73, 74, 82, 83, 92;
Vexatorella 104, 106, 107;
Protea 115, 125, 135, 136, 150, 162, 164, 175, 179, 184, 188, 189;
Leucadendron 194, 202, 209, 214, 231, 235, 236, 237, 245, 246, 250, 253, 262, 263, 267, 268, 280, 281;
Aulax 285;
Paranomus 289, 291, 292, 295, 302;
Serruria 306, 308, 314, 317, 318, 336, 338, 339, 348.

no longer threatened:

Leucospermum glabrum (60): (1985: r, 1982: v) Known from many (usually small) populations over 80 km-long area. No known threats.

L. catherinae (77): (1985: r, 1982: n) Known from very many (usually small) populations. No known threats.

Protea vogtsii (167): (1985-2: i) Known from many localities in two mountain ranges. May be quite common as it has an inconspicuous growth form. No known threats.

P. pityphila (190): (1985: v, 1982: r) Known from many small populations along a 30 km-long area. Only one population is under any threat (by roadbuilding).

Paranomus esterhuyseniae (297): (1985: r, 1982: i) Locally common.

rare:

Sorocephalus capitatus (30): (1982-5: n) Known from only two populations separated by 40 km.

Leucadendron sorocephaloides (212): (1985: v; 1982: n) Known from several populations over a 70 km long area. Grazing and too-frequent burning are possible threats, but additional populations probably exist.

L. argenteum (217): (1982-5: v) Occurring at three widely separate localities, two of which may have been planted. Two of the localities contain populations in existing reserves.

vulnerable:

Mimetes hirtus (9): (1985: r, 1982: n) Threatened by urbanization and draining of marshy habitats. Present in two reserves.

Diastella proteoides (21): (1985: v, 1982: n) Known from 60 km-long area on Cape flats. Seriously threatened by urbanization, agriculture and alien infestation.

Leucospermum formosum (76): (1985: v; 1982:r) Known from five localities over 210 km-long area. Apparently extinct at one of the localities. Threats: afforestation, low seed production.

L. tomentosum (84): (1985: v, 1982: r) Known from 65 km-long area on western-Cape flats. Threats: agriculture, grazing and alien infestation.

Protea restionifolia (157): (1985: n, 1982: n) A common species in habitats currently threatened by agricultural expansion.

P. decurrens (182): (1982-5: n) Occurring on ferricrete and silcrete cappings on shales over a 200 km-long area. These habitats are being converted to agriculture.

Leucadendron galpini (201): (1985: n; 1982: r) Known from many dense populations along sandy valley bottoms over a 110 km-long area. These habitats are being converted to planted pasture.

Serruria cyanoides (313): (1985: n; 1982: r) Virtually eliminated from localities on the Cape Flats, this species is still present in sandy areas at higher elevations.

S. millefolia (334): (1985: n, 1982: i) Known from a 150 km-long area, several populations have been eradicated by agriculture.

endangered:

Sorocephalus imbricatus (29): No change in status. Two populations are known separated by 100 km. One population consisted of three plants in 1968 and two plants in 1983, the other has not been relocated since its original discovery at the turn of the century.

Leucadendron levisanus (198): No change in status. Once occurring in many small populations over a 70 km-long area, this species has been heavily impacted by urbanization, surviving mainly in road verges.

L. laxum (220): (1982-5: n) Known from many localities over a 80 km-long area. Threatened by agriculture in its valley bottom habitat.

L. chamelaea (243): No change in status. Known from 18 populations in a 80 km-long area. Seriously threatened agriculture.

L. cryptocephalum (265): (1985: v; 1982: e) Known from three localities over a 130 km-long area. Apparently extinct at one, one population has only a very few individuals and the third has been heavily impacted by agriculture.

Serruria aemula (307): No change in status. Previously widespread in large populations on sandy flats over a 30 km-long area. Reduced to a few isolated, small remnants within vacant lots and road verges in urban area. Additionally threatened by alien infestation.

Serruria furcellata (324): No change in status. A Cape Flats species heavily impacted by urbanization occurring within a 75 km^2 area. Currently known to exist at only two localities, separated by 6 km. One locality is being developed for housing.

S. roxburgii (341): No change in status. Known from three localities in a 30 km-long area. Agriculture is the most serious threat, with alien infestation and over-frequent burning also contributing.

S. trilopha (343): No change in status. Known from four localities in a 35 km-long area. Threatened by urbanization.

4. Rare species with a large geographical range (Widespread, Restricted, Sparse)

not threatened:

Mimetes 10;
Diastella 17;
Spatalla 36;
Protea 116, 152, 169;
Leucadendron 207, 223;
Paranomus 296;
Serruria 342.

no longer threatened:

Leucadendron cinereum (199): (1982-5: v) Known from many localities in a 100 km-long range in the west-coast lowlands. Although many populations have been destroyed by agriculture, the species is under no immediate threat, unless urbanization and agriculture expand into marginal lands.

Serruria zeyheri (347): (1982-5: r) Probably more common than was appreciated.

rare:

Mimetes splendidus (4): (1985: v, 1982: r) Several (usually very small) populations totalling 500 are known over a 300 km range. More populations may exist. Threats: Aseasonal fires.

Spatalla propinqua (40): (1982-5: i) Known from several small populations on peat substratum on south-facing slopes over a 70 km-long area.

Serruria leipoldtii (331): No change in status.

S. pinnata (337): (1985: v; 1982: n) Occurring in many small populations on shales over a wide area, there are few threats to this species at present, although the western form (*S. pinnata* sensu RBr) is threatened by agriculture.

5. Species with only a small geographical range (Localized, Broad, Dense)

not threatened:

Leucospermum 58.

rare:

Orothamnus 13 (See Boucher 1981b).

vulnerable:

Leucospermum heterophyllum (91): (1982-5: n) Occurring on conglomerates and sandy soils in a localized area 30 km long. Threats: agriculture.

Protea angustata (171): No change in status. Occurring on shales and sands, often as small sparse populations within a 60 km-long coastal range. Threats: urbanization.

Leucadendron thymifolium (197): Once probably widespread in a 20 km long range, now extant at three small populations.

endangered:

Leucadendron macowanii (252): No change in status. Known from two localities 25 km apart. Extinct at one it is currently confined to four small populations in a 2km-long area.

6. The "impossible category" (Localized, Broad, Sparse)

- - -

7. Classical restricted endemic (Localized, Restricted, Dense)

not threatened:

Mimetes 2, 3;
Diastella 19, 20;
Spatalla 42, 53;
Leucospermum 66, 81, 99, 100;
Vexatorella 103;
Protea 146, 155;
Leucadendron 221, 222, 228, 247;
Paranomus 299;
Serruria 325, 340, 345.

no longer threatened:

Leucospermum 61, 65, 93, 96, 98, 101, 102;
Protea 127;
Leucadendron 204, 224, 232, 234, 249;
Paranomus 290.

rare:

Mimetes 7, 12, *chry*;
Diastella 15;
Spatalla 39, 41, 43, 46;
Leucospermum 79, 95;
Vexatorella 105;
Protea 114, 126, 149, 163, 178;
Leucadendron 195, 203, 213, 226, 233, 248, 271;
Paranomus 287, 293, 298, 300, 303, 304;
Serruria 312, 321, 327, 333.

vulnerable:

Diastella 14;
Leucospermum 62, 86;
Protea 139, 191;
Leucadendron 208, 230, 240.

endangered:

Diastella 22
Sorocephalus 23;
Spatalla 34, 47, 49;
Leucospermum 63;
Protea 192;
Leucadendron 206, 239, 241, 244, 258, 260;
Serruria 344.

extinct

Sorocephalus tenuifolius (33);
Leucadendron spirale (278).

8. Truly rare species (Localized, Restricted, Sparse)

not threatened:

Diastella 16, 18;
Spatalla 48, 50;
Protea 129;
Serruria 320, 326.

rare:

Mimetes 5, 6, 11;
Sorocephalus 24, 28;
Leucospermum 69, 75, 87;
Leucadendron 211, 227, 259;
Paranomus 301;
Serruria 316, 330, 346, 349, 350, 351.

vulnerable:

Serruria 311, 322.

endangered:

Sorocephalus 26, 27, 31;
Leucadendron 218, 242, 264;
Serruria 332.

extinct:

Mimetes stokoei (8)

Appendix Five

RESCUE:

An iterative programme for selecting a nature reserve system based on different criteria for selecting priority grid squares.

Note that the section on apparent species (intended to insert missing data in obvious gaps within a species distributional range according to different resolutions, as specified) was never developed. The outline of the intended subroutine has been retained should it require developing in the future.

Section one: printout of options available as requested by RESCUE.

```
                PARAMETER DATA:

How many sites are there?
       130

How many species are there?
       350

How many records (specimens) in the data set?
      2000

How is the data provided:
  if the list is provide in site, species, value order then type 1
  else if in  species, sites,value order then type 2
         2

What is the maximum number of species per line input (columns 1-3)
and the format of the data (only integer vals)?
finish off the input with zero in the site column
        16

Do you wish to check your data for duplicate records  data out of range?
  HIGHLY RECOMMENDED FOR FIRST RUNS
 Yes = 1; No (default) = 0
yes:  1
```

```
                PRINTOUT OPTIONS:

Do you wish to see species number per site after each loop:
 Yes: type 1,  Default = No: type 0
 no:  0

Do you wish to see calculations for all existing reserves:
 Yes: type 1,  Default = No: type 0
 no:  0

Do you wish to suppress all output except reserve names and spp and populations conserved?
 Yes: type 1, No: type 0
 no:  0

                DATA MODIFICATION:  DELETIONS:

Do you wish to omit any sites?  If so,  record the number of sites
and on the next line provide sites in I4 format (maximum 20 per line).
 If no merely type 0 on one line
         0

Do you wish to omit any species? If so, record number of species and
on the next line provide sites in I4 format  (maximum 20 / line).
 If no merely type 0 on one line
         0

      DATA MODIFICATION OPTIONS: APPARENT SPECIES:

Do you wish to use apparent species to select reserves?
If Yes: type the number of linear squares over which apparent species must be assigned.
 Apparent species are only assigned after unwanted sites and spp are removed.
A file called inappr.doc must be available for collecting the list of apparent species:
 if you wish to use this file in future make sure that no sites or species are omitted
        in your first run
In subsequent runs type 99 to use the data in file inappr.doc:
unwanted species and sites are removed later as required
Default = No: type 0
         0

Do you wish to consider apparent species conserved?:
Yes: type 1,  Default = No: type 0
         0
```

```
                RESERVE OPTIONS

What is the maximum number of reserves to be created? For default (=number of sites) type 0
         0

In how many reserves must each species be preserved?
         1

How many reserves already exist?  If any,  record the number of sites
 and on the next line provide sites in I4 format (maximum 20 per line,in sequence).
If no merely  type 0 on one line
         9

Preselected (existing) reserves =
  129    33   119   116    61    21    15     9     4


                RESERVE SELECTION OPTIONS

What algorithm would you like to use to select sites as reserves?  options are:
 1. Species richness only
 2. Species richness of unconserved species only
 3. Species richness of unconserved real+app species
 4. Remaining unique species only
 5. Weighted by sum of values provided
 0 = Default - Weighted by sum of values,
where value for species =   1 / abundance (i.e. 1/# sites present)
         0

What algorithm would you like to use to resolve conflicts in selecting sites as reserves?
 1. Species richness only
 2. Species richness of unconserved species only
 3. Species richness of unconserved real+app species
 4. Remaining unique species only
 5. Weighted by sum of values provided
 0 = Default - Weighted by sum of values,
where value for species =   1 / abundance (i.e. 1/# sites present)
         0

Do you wish to select reserves at random?
if no,  then type 0
if yes, then type in the number of reserves;
 followed by a seed number (postive uneven about 5 digits) for the random number generator
          on the next line
         0

         0
```

```
 Please provide your data:
 signify end of data with a zero in the site column

Reading in data

Summary of species input:

127   1/128   1/117   1/118   1/119   1/  7   2/  6   2/ 13   2/ 19   2/ 30   2/
 43   2/ 44   2/ 45   2/ 59   2/ 60   2/ 61   2/ 75   2/ 76   2/123   2/124   2/
        [[etc]]
115 318/116 318/117 318/118 318/119 318/120 318/121 318/122 318/123 318/124 318/
125 318/126 318/127 318/128 318/129 244/129 259/129 264/129 313/

Checking for data out of range

size of input data list  =   6988
Number of remaining unassigned specimens is:      6988

Apparent species were not requested
  random assigning not s requested


 removing reserve no     1  as site no   129

sum of species  conserved is:    48  in    48  populations


 removing reserve no     2  as site no    33

sum of species  conserved is:    57  in    94  populations

        [[etc]]

 removing reserve no     9  as site no     4

sum of species  conserved is:   149  in   610  populations


existing reserves removed: data dump follows
 20 137/ 19 137/ 18 137/ 17 137/ 16 137/ 94 206/ 93 206/ 92 206/ 80 206/ 79 206/
 78 206/ 63 206/ 64 206/ 48 206/ 62 206/ 14 137/ 13 137/ 12 137/ 11 137/  1 137/
        [[etc]]
 95 180/ 94 180/ 93 180/110 180/109 180/108 180/107 180/106 180/105 180/117 180/
123 311/122 311/121 311/120 311/ 54 305/ 55 305/ 26 309/ 25 309/ 24 309/
```

```
 THE INITIAL SITUATION IS:


species number   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
totl occurances  5 21 54  7 31 20 25 16  0117 19 37  0 27  0 46  6 12  1  1 17  1  7  0  3
number reserves  1  1  4  1  0  1  2  4  0  6  4  2  0  4  0  1  0  0  0  0  1  0  0  0  0
        [[etc]]

sum of species  conserved is:   149  in   610  populations


 resolved:  site   62 chosen

Selection of reserve no     10
Selected as site            62
Number of remaining unassigned specimens is:       198

species number   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
totl occurances  5 21 54  7 31 20 25 16  0117 19 37  0 27  0 46  6 12  1  1 17  1  7  0  3
number reserves  1  1  5  1  1  1  2  4  0  7  4  2  0  4  0  1  0  0  1  0  2  0  1  0  0
        [[etc]]

sum of species  conserved is:   157  in   652  populations


 resolved:  site   95 chosen

Selection of reserve no     11
Selected as site            95
Number of remaining unassigned specimens is:       134

species number   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
totl occurances  5 21 54  7 31 20 25 16  0117 19 37  0 27  0 46  6 12  1  1 17  1  7  0  3
number reserves  1  1  5  1  1  1  2  4  0  8  4  2  0  4  0  1  0  0  1  0  2  1  1  0  0
        [[etc]]

sum of species  conserved is:   161  in   691  populations


        [[etc]]


option conflict on choosing sites:  89 103
option conflict on choosing sites not resolved:
site  89  chosen by weighted abundance as containing most rares out of sites (in < order):
  89  103

Selection of reserve no     14
Selected as site            89
Number of remaining unassigned specimens is:         0

species number   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
totl occurances  5 21 54  7 31 20 25 16  0117 19 37  0 27  0 46  6 12  1  1 17  1  7  0  3
number reserves  1  3  7  1  3  2  3  5  0 11  4  3  0  5  0  1  1  1  1  1  3  1  2  0  1
        [[etc]]

sum of species  conserved is:   175  in  1077  populations


All the species conserved as required: ending now

FORTRAN STOP
```

Section two: "RESCUE" programme listing.

A electronic copy of the programme can be obtained from the Director, FitzPatrick Institute, University of Cape Town. However, it does not print some of the diagnostic data provided herein for programme termination which results from data out of range or duplicate data during the optional data-checking subroutine. In addition, file and directory names will vary between computing systems.

PROGRAMME "RESCUE"

A G Rebelo

June 1989

This programme iteratively determines the spatial configuration of reserves within a rastered area, so as to preserve all the species the specified number of times, in the minimum number of grid squares using one of the algorithms provided.

- Use of this programme is free, on condition that indemnity for any errors within or generated by the programme is accepted.
- The section on apparent species has not been completed and has not been tested. Do not use it as is. The skeleton of the algorithm is provided for those who wish to develop it further.
- The programme uses features specific to the VAX[VMS] system and will require minor modifications for use on other computing systems.

```
Ruler Line
        1         2         3         4         5         6         7
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012

C   YOU WILL NEED THE FOLLOWING FILES:
C     inpt.doc:  run-time parameters:  see subroutine parait for details
C     raster.data:  your actual data in the form of:
C               species (sites [value]) OR  site (species [value])
C               where () and [] denote multiple & optional entries per line

C   SHOULD YOU WISH TO USE APPARENT SPECIES YOU WILL NEED:
C    inappr.doc:  the file containing the apparent species data
C                 these data can be generated by the programme
C    irdc.doc: coordinates of the grid system used to generate apparent spp

C   A NOTE ON UNIQUE SPECIES:
C     "Unique species" are species confined to a single site in the data
C                      matrix.
C     "Remaining unique species" are assigned to species (not apparent
C                      species) restricted to a single remaining site.

C   A NOTE ON APPARENT SPECIES:
C       Apparent species are only assigned to sites which have at least one
C       species.  They are not computed for sites which have been excluded
C       from the analysis.  They are computed before reserve selection
C       begins and are thereafter condidered separately to (if required),
C        but otherwise treated as,  normal species.  They are not available
C       for consideration as "unique" species.

C   A NOTE ON UPGRADING THE PROGRAMME:
C      If IMAXLI is changed:  then change TEST in inchit
C      If IMAXSI is changed:  then change ARSTA in slctit
C      If IMAXSP is changed:  then change ARNOSP in valuit
C      Note that  ISTAOP, ISTOAS,  and ISTARE should equal IMAXSI
C      It is wise to set IMAXAL equal to IMAXLI
```

```
c   LISTING OF DECLARATIONS
c
c       character*77 FORMAN !  format for data in
c       integer  INPTT    !  value for toggling spp/site and site/spp input
c       integer  MAXALT   !  size of array ARALT (conserved spp)
c       integer  MAXAPP   !  current size of array ARAPPR
c       integer  MAXLIS   !  size of array ARARR:  updated
c       integer  MAXREC   !  maximum number species per line data input
c       integer  MAXRES   !  maximum number of reserves required
c       integer  MAXSIT   !  maximum number of sites
c       integer  MAXSPP   !  maximum number of species
c       integer  NUMRES   !  incremental reserve counter
c       integer  RDCOOR   !  unit number for coordinate file
c       integer  RDDATA   !  unit number for data input
c       integer  RDPARA   !  unit number for parameter data
c       integer  STAAPC   !  apparent species conserved option
c       integer  STAAPS   !  apparent species to select reserves option
c       integer  STACON   !  counter for number of preselected reserves
c       integer  STACSE   !  choice of selection
c       integer  STACRC   !  choice to resolve option conflict
c       integer  STAOPP   !  size of array AROPP no excluded species
c       integer  STAOST   !  size of array ARROST no excluded sites
c       integer  STAPRE   !  minimum # reserves per species
c       integer  STAPTR   !  intermediate printing option
c       integer  STARES   !  number of preexisting reserves
c       integer  STARPP   !  report back on existing reserves
c       integer  STNAME   !  site with the highest conservation value
c       integer  STFIRS   !  first time check of data
c       integer  STRAND   !  selection of reserves at random
c       integer  STRANO   !  no of reserves in random selection
c       integer  STINHI   !  inhibition of output
c       integer  STSEED   !  seed # for random number generator for reserves
c       integer  VAL      !  main prog var for selecting array elements
c       integer  WRUNIT   !  unit for output

c       integer  ARALT(maxalt,3)  !  site,spp,value: dump conserved spp
c       integer  ARARR(maxlis,3)  !  site,spp,value:        data matrix
c       integer  ARAPPR(maxapp,3) !  site,spp,value:   apparent  matrix
c       integer  ARROPP(staopp)   !  spp:               excluded species
c       integer  ARROST(staost)   !  site:                excluded sites
c       integer  ARRRES(stares)   !  site:              existing reserves
c -     integer  ARSIT(maxsit,4)  !  remaining spp, app spp, unique spp, val
c       integer  ARSUN(maxsit,4)  !  original spp,  app spp, unique spp, val
c       integer  ARSPP(maxspp,2)  !  tot occurrencs; # reserves for each spp
c
c         LISTING OF SUBROUTINES

c       subroutine  APCNVT  !  assigns apparent species
c       subroutine  APREAD  !  reads in apparent species
c -     subroutine  CHCKIT  !  checks array sizes versus compiled sizes
c -     subroutine  INCHIT  !  checks input data within specified range
c       subroutine  PARAIT  !  reads in the parameters to run programme
c       subroutine  PARITY  !  optimizes size of ARAPPR
c -     subroutine  PRNTIT  !  prints results
c       subroutine  QUKREM  !  removes reserves without giving printouts
c -     subroutine  READIT  !  reads in the raw data
c -     subroutine  RONDIT  !  reads numbers of sites/squares for omission
c -     subroutine  SLCTIT  !  select the most important reserve
c -     subroutine  SIREIT  !  removes unwanted sites/squares from main list
c -     subroutine  SORTIT  !  sums the current species status for each site
c -     subroutine  STATIT  !  prints intermediate data
c -     subroutine  STRPIT  !  removes zeros to shorten the data arrays
c -     subroutine  TALYIT  !  add up spp and ascertain conservation status
c -     subroutine  UNIQIT  !  determines the number of unique species
c -     subroutine  VALUIT  !  assigns the priority values for selection
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                    INITIALIZE PARAMETER CONSTANTS

      Parameter (IMAXAP = 10000)
      Parameter (IMAXLI = 10000)
      Parameter (IMAXAL = 10000)
      Parameter (IMAXSI =  2500)
      Parameter (ISTAOP =  2500)
      Parameter (ISTAOS =  2500)
      Parameter (ISTARE =  2500)
      Parameter (IMAXSP =  2500)
      Parameter (IMAXCO =    30)
      Parameter (IRDCOO =    14)
      Parameter (IRDDAT =     5)
      Parameter (IRDPAR =     5)
      Parameter (IWRUNT =     6)

      dimension ARALT(IMAXAL,3)
      dimension ARARR(IMAXLI,3)
      dimension ARAPPR(IMAXAP,3)
      dimension ARROPP(ISTAOP)
      dimension ARROST(ISTAOS)
      dimension ARRRES(ISTARE)
      dimension ARSIT(IMAXSI,4)
      dimension ARSUN(IMAXSI,4)
      dimension ARSPP(IMAXSP,2)

      character*77  FORMAN
      integer  INPTT, MAXALT, MAXAPP, MAXLIS, MAXREC, MAXRES, MAXSIT,
      integer  MAXSPP, NUMRES, STAAPC, STAAPS, STACON, STACSE, STACRC,
      integer  STAOPP, STAOST, STAPRE, STAPTR, STARES, STARPP, STFIRS,
      integer  STRAND, STRANO, STINHI, STSEED, STNAME, VAL

      integer  ARALT, ARARR, ARAPPR, ARROPP, ARROST, ARRRES, ARSIT
      integer  ARSUN, ARSPP

      Open (5,file='inpt.doc')
      Open (14,file='irdc.doc')
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C    MAIN PROGRAMME:  SUBROUTINE SELECTOR

C                INITIALIZE UNIQUE ARRAYS AND VARIABLES

      maxalt = 0
      numres = 0

      data ararr  /imaxli*0,imaxli*0,imaxli*0/
      data aralt  /imaxal*0,imaxal*0,imaxal*0/
      data arappr /imaxap*0,imaxap*0,imaxap*0/
      data arropp /istaop*0/
      data arrost /istaos*0/
      data arrres /istare*0/
      data arsit  /imaxsi*0,imaxsi*0,imaxsi*0,imaxsi*0/
      data arsun  /imaxsi*0,imaxsi*0,imaxsi*0,imaxsi*0/
      data arspp  /imaxsp*0,imaxsp*0/

15    format('1 Please provide your data:',/,'  signify end of data
     c with a zero in the site column',/)
25    format(' Reading in data',/)
35    format(' Checking for data out of range',/)
45    format('0Removing unwanted sites',/)
55    format('0Removing unwanted species',/)
65    format('0Assigning apparent species:',/)
75    format('0Apparent species were not requested')
105   format(26i5)
125   format('     ',i10,' apparent species records were assigned')
135   format(' Summary of species input as (/spp, site/) X 10:',/)
145   format(10(2i5,'/'))
155   format(' Listing of data inhibited: printout opt #3',/)
305   format(' Number of remaining unassigned specimens is:',i10,/)
315   format(' Reading apparent species from file inappr.doc')
325   format(' Summary of apparent species assigned:'/)
335   format(' Number of apparent specimens is:',i10,/)
445   format('1 Data dump follows:',/,
     c     ' 10 X (/spp, site/) in order within data array')

c                          READ IN PARAMETERS

      call parait (iwrunt, irdpar, maxsit, imaxsi, maxspp, imaxsp,
     c      maxlis, imaxli, maxrec, forman, staptr, starpp, staost,
     c      istaos, staopp, istaop, staaps, staapc, maxres, stapre,
     c      stares, istare, stacse, stacrc, arrost, arropp, arrres,
     c      inptt,  strand, strano, stinhi, stseed, stfirs)

C                          READ IN DATA

      write(iwrunt,15)
      write(iwrunt,25)
      call readit (irddat, maxrec, ararr, maxlis, forman,imaxli,inptt)
      if (stinhi.eq.0)then
        write(iwrunt,135)
        write(iwrunt,145)(ararr(i,1),ararr(i,2), i = 1,maxlis)
      else
        write(iwrunt,155)
      end if

c                     CHECK FOR DATA OUT OF RANGE

      if (stfirs.eq.1) then
        write(iwrunt,35)
        call inchit (ararr,imaxli,maxlis,maxspp,maxsit,iwrunt)
      else
      end if
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                        REMOVE UNWANTED SITES
```

```
      val = 1
      if (staost.gt.0) then
        write(iwrunt,45)
        call sireit (staost, arrost, val, maxlis, ararr, imaxli,
     c                  istaos)
        write(iwrunt,105)(arrost(i), i=1,staost)
      end if
```

```
C                        REMOVE UNWANTED SPECIES
```

```
      val = 2
      if (staopp.gt.0) then
        write(iwrunt,55)
        call sireit (staopp, arropp, val, maxlis, ararr, imaxli,
     c                  istaop)
        write(iwrunt,105)(arropp(i), i=1,staopp)
      end if
```

```
c                    HOUSEWORK:  STRIP ARRAY OF ZEROS
```

```
      if (staopp.gt.0.or.staost.gt.0)
     c                   call strpit (maxlis, ararr, imaxli)
      write (iwrunt,305) maxlis
```

```
C                        ASSIGN APPARENT SPECIES
```

```
      if (staaps.gt.0.and.staaps.ne.99)  then
         write(iwrunt,65)
         call apcnvt (irdcoo, staaps, ararr, maxlis, arappr,
     c       maxapp, maxsit, maxspp, imaxap, imaxli, imaxsi,iwrunt)
         write(iwrunt,125)maxapp
      else if (staaps.eq.99) then
         write(iwrunt,315)
         call apread (arappr, imaxap, maxapp,maxsit,maxspp,iwrunt)
      else
         write(iwrunt,75)
      end if

      if (staaps.gt.0)  then
```

```
c                          SUMMARIZE APP DATA
```

```
      write(iwrunt,325)
      write(iwrunt,145)(arappr(i,1),arappr(i,2), i = 1,maxapp)
```

```
C                    REMOVE APP SPP FROM UNWANTED SITES
```

```
      val = 1
      if (staost.gt.0) then
        write(iwrunt,45)
        call sireit (staost, arrost, val, maxapp, arappr, imaxap,
     c                  istaos)
        write(iwrunt,105)(arrost(i), i=1,staost)
      end if
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                        REMOVE UNWANTED SPECIES
```

```
          val = 2
          if (staopp.gt.0) then
            write(iwrunt,55)
            call sireit (staopp, arropp, val, maxapp, ararr, imaxap,
     c                   istaop)
            write(iwrunt,105)(arropp(i), i=1,staopp)
          end if
```

```
c                    HOUSEWORK:  STRIP ARRAY OF ZEROS
```

```
          if (staopp.gt.0.or.staost.gt.0)
     c                    call strpit (maxapp, arappr, imaxap)
        write (iwrunt,305) maxapp
        else
        end if

C    AT LAST WE ARE READY TO BEGIN THE PROGRAMME
```

```
C                    TALLY UP TOTAL OCCURRENCES PER SP
```

```
           do 300 i = 1,maxlis
             arspp(ararr(i,2),1) = arspp(ararr(i,2),1) + 1
300        continue
```

```
C                        DETERMINE UNIQUE SPECIES
```

```
          val = 3
        call uniqit (val, ararr, maxlis, arsun, maxsit, maxspp,
     c                imaxli,imaxsi)
```

```
C                                SORT DATA
```

```
        val = 1
        call sortit (val, arsun, ararr, maxlis, maxsit, imaxli, imaxsi)
```

```
C                          DETERMINE SPP VALUES
```

```
        val = 4
        call valuit (val, arsun, ararr, maxlis ,maxsit, stacse, maxspp
     c                ,imaxsp, imaxli, imaxsi)
```

```
C                          SORT APPARENT DATA
```

```
        val = 2
        if (staaps.gt.0) call sortit
     c (val, arsun, arappr, maxapp, maxsit, imaxap, imaxsi)
```

```
c                  ASSIGN RESERVES AT RANDOM IF REQUIRED
```

```
        If (strand.eq.1) then
          call random
     c    (arsun,imaxsi,maxsit,arrres,istare,stares,stseed,strano)
345     format(' The following sequence of reserves has been randomly
     c assigned',/,30(20i6,/))
          write (iwrunt,345) (arrres(i), i = stares-strano+1,stares)
        else
          write (iwrunt,*)'  random assigning not requested'
        end if
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                    FOR NO REPORT BACK REMOVE RESERVES
```

```
      if(starpp.eq.0.and.stares.gt.0) call qukrem
     c  (iwrunt, ararr, maxlis, arrres, stares, arspp, maxspp,
     c imaxli,istare, imaxsp, imaxal, maxalt, aralt, stapre,numres,
     c stinhi)

      write(iwrunt,415)
415   format('1  THE INITIAL SITUATION IS:'///)
```

```
c                    RETURN FROM LOOP & PRINT RESULTS
```

```
1001  continue

      if (stinhi.eq.0) then
           call prntit (iwrunt, arspp, maxspp, imaxsp,stinhi)
      else
         if (numres.eq.0.or.maxlis.lt.1.or.numres.eq.stares.or
     c    .numres.eq.maxres) then
            stinhi = 0
            call prntit (iwrunt, arspp, maxspp, imaxsp,stinhi)
            stinhi = 1
         else
            call prntit (iwrunt, arspp, maxspp, imaxsp,stinhi)
          end if
      end if
```

```
c                    CHECK IF PROGRAMME TO CONTINUE
```

```
      if (maxlis.lt.1) then
425   format(' All the species conserved as required: ending now')
         Write(iwrunt,425)
         go to 3300
      else
```

```
C                    ASSIGN REMAINING UNIQUE SPP
```

```
      val = 3
      call uniqit (val, ararr, maxlis, arsit, maxsit, maxspp,
     c                imaxli,imaxsi)
```

```
C                              SORT DATA
```

```
C                          DETERMINE SPP VALUES
```

```
      val = 4
      call valuit (val, arsit, ararr, maxlis, maxsit, stacse, maxspp,
     c                imaxsp, imaxli, imaxsi)
```

```
c                          COUNT THE SPECIES
```

```
      val = 1
      call sortit (val, arsit, ararr, maxlis, maxsit, imaxli, imaxsi)
```

```
C                          SORT APPARENT DATA
```

```
      val = 2
      if (staaps.gt.0)
     ccall sortit (val, arsit, arappr, maxapp, maxsit, imaxap, imaxsi)
```

```
        1         2         3         4         5         6         7
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                    PRINT INTERMEDIATE RESULTS
```

```
          if(staptr.eq.1)
     c      call statit (iwrunt, staaps, arsit, arsun, maxsit, imaxsi)

          if (maxres.le.numres) then
435     format(' All the reserves are assigned:  execution ends')
            Write(iwrunt,435)
            call endit (iwrunt, ararr, maxlis, imaxli)
          go to 3300
          else
            numres = numres + 1
            if (stares.ge.numres) then
              stacon = arrres(numres)
            else
              stacon = 0
            end if
          end if
        end if
```

```
C                    IF NOT FINISHED:  CONTINUE
```

```
C                    SELECT RESERVES, JUGGLE SPP
```

```
c                PRINT ALL DATA EVERY FIFTY RESERVES
```

```
        if (stinhi.eq.0)then
          if(numres.eq.50.or.numres.eq.100.or.numres.eq.150.or.
     c      numres.eq.200.or.numres.eq.250) then
           write(iwrunt,445)
           write(iwrunt,145)(ararr(i,1),ararr(i,2), i = 1,maxlis)
          else
          end if
        else
        end if
```

```
c            CHECK IF ALL PRESELECTED SITES ARE ASSIGNED
```

```
        if (stacon.gt.0) then
            stname = stacon
            val = 2
        else
```

```
C                ELSE CALCULATE VALUES + SELECT
```

```
            call slctit (iwrunt, stacse, stname, imaxco, maxsit,
     c                   imaxsi, val, arsun, arsit)
          end if
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                CONTINUATION OF START IF PRE-RESERVED
```

```
265    format('1Selection of reserve no  ',i5,/,
     c        ' Selected as site          ',i5)
275    format('1Reserve no ',i5,/,' Preselected as site no ',i5)
266    format('  ',/,' Selection of reserve no  ',i5,/,
     c        ' Selected as site          ',i5)
276    format('  ',/,' Reserve no ',i5,/,
     c        ' Preselected as site no ',i5)

2701   continue
c
       if (stinhi.eq.0)then
         if (val.le.1) then
           write(iwrunt,265) numres, stname
         else
           write(iwrunt,275) numres, stname
         end if
       else
         if (val.le.1) then
           write(iwrunt,266) numres, stname
         else
           write(iwrunt,276) numres, stname
         end if
       end if
```

```
c                  REMOVE SITES, JUGGLE & REMOVE SPECIES
```

```
       call talyit (imaxli, maxlis, ararr, imaxsp, maxspp,
     c    imaxal, maxalt, aralt, arspp, stname, stapre, iwrunt)
```

```
c                               DO HOUSEWORK
```

```
       call strpit (maxlis, ararr, imaxli)
       call strpit (maxalt, aralt, imaxal)
       if (staapc.gt.0) call strpit (maxapp, arappr, imaxap)
       write (iwrunt,305) maxlis
```

```
c                       GO BACK AND CHECK IF FINISHED
```

```
       go to 1001
3300   continue
       close(unit=5)
       close(unit=14)

       stop
       end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**************************************************************************
      subroutine apcnvt (irdcoo, staaps, ararr, maxlis, arappr,
     c         maxapp, maxsit, maxspp, imaxap, imaxli, imaxsi,iwrunt)
C          THIS SUBROUTINE ASSIGNS THE APPARENT SPECIES TO THE DATA
c
c           NB THIS SUBROUTINE HAS NOT BEEN COMPLETED OR CHECKED!
c
c_____________________________________________________________________

c      character*74 FORMIN          ! format for reading in data
c      character*74 FOREIN          ! variable format for writing to iwrout
C      integer CHKAPP               ! check on size of arappr
c      integer CORDNR               ! no of coordinates per line
c      real    CODNM (50,4)         ! coordinate name = (o,',o,')
c      integer COODNM(50,4)         ! coordinate name = ',',-,-)
c      integer COODMA(8,11,2)       ! coordinate conversion matrix
c      integer GRDUNT               ! grid incremental unit
c      integer MAXAPP               ! no of app records - size of arappr
c      integer MAXLIS               ! no of records - size of ararr
c      integer MAXSIT               ! no of sites
c      integer SITSIT(400)          ! (1) site numbers;
c                                   ! (2) species in target site
c      integer SITRCH               ! size of sitsit in '2'
c      integer STAAPS               ! units to be incremented for assigns
c      integer ARAPPR(maxapp,3)     ! apparent data
c      integer ARARR(maxlis,3)      ! data
c      real    ARCOOD(maxsit,2)     ! coordinate data
c      integer IWROUT               ! output for setting ARAPPR to file

      character*74 FORMIN
      character*74 FOREIN
      integer CHKAPP
      integer CORDNR
      real    CODNM (50,4)
      integer COODNM(50,2)
      integer COODMA(8,11,2)
      integer GRDUNT
      integer IMAXAP,  IMAXLI,  IMAXSI,  IRDCOO,  IWRUNT
      integer MAXAPP,  MAXLIS,  MAXSIT,  MAXSPP
      integer SITSIT(360)
      integer SITRCH
      integer STAAPS
      integer ARAPPR(imaxap,3)
      integer ARARR(imaxli,3)
      integer ARCOOD(2000,2)
      integer IWROUT

      parameter (iwrout = 9)

      open (iwrout, file='inappr.doc')

15    format(i3,f3.0,a74)
25    format(' sorry the coordinate space allocated in subroutine
     c apcnvt is too small - make arcood(2000) = imaxsi (= # sites)')
35    format('1Too many species are required for the allocated size
     c of the matrix ARAPPR:'/'rerun programme with MAXAPP larger.',
     c /, ' At time of crash',i5,'  sites had been processed')
```

```
c                    CHECK ARRAY BOUNDS NOT EXCEEDED
```

```
      if (maxsit.gt.2000)then
      write(iwrunt,25)
      stop
      end if

      maxapp = 0
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                        READ IN COORDINATE DATA
```

```
      read(irdcoo,15) cordnr,codnm(1,1),formin
        grdunt = codnm(1,1) * 100
      read(irdcoo,formin)
     c              (sitsit(i),(codnm(i,j), j = 1,4), i = 1,cordnr)
100   continue
```

```
c                CONVERT COORDINATE DATA TO DECIMAL DATA
```

```
      DO 150 i = 1,cordnr
         coodnm(i,1) = codnm(i,1) * 6000 + codnm(i,2) * 100
         coodnm(i,2) = codnm(i,3) * 6000 + codnm(i,4) * 100
150   continue

      do 200 i=1,cordnr
          if (sitsit(i).le.maxsi) then
             if(coodnm(i,1).gt.0)then
                arcood(sitsit(i),1) = coodnm(i,1)
                arcood(sitsit(i),2) = coodnm(i,2)
                maxapp = maxapp + 1
             else
             end if
          else
9175         format(' WARNING:  site value in coordinate matrix too
     clarge!')
             write(iwrunt,9175)
          end if
200   continue

      read(irdcoo,formin,iostat = ioerr,end=50,err=50)
     c               (sitsit(i),(codnm(i,j), j = 1,4), i = 1,cordnr)
50    if (ioerr.eq.0) then
      go to 100
      else
      end if
```

```
c                        REINITIALIZE WORK MATRIX
```

```
      do 300 i = 1,360
        sitsit(i)=0
300   continue
      maxapp=1
      chkapp=1000
      l = 1
```

```
c                  ASSIGN APP SPP FOR ALL TARGET SITES
```

```
      do 1000 m = 1,maxsit
```

```
c                     FIND SPECIES IN SPECIFIC SITE
```

```
        do 350 i = 1,maxlis
          if (ararr(i,1).eq.m) then
             sitsit(l) = ararr(i,2)
             l = l + 1
           end if
350     continue
        sitrch = l
```

```
c                FIND NEIGHBORING SITES IN UNITS OF grdunt
```

```
      l = 1

        do 460 j = 1,(100*(staaps+1)),grdunt
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                    DIRECTIONS: N,NE,E,SE,S,SW,W,NW
```

```
            coodma(1,l,1) = arcood(i,1) - j
            coodma(1,l,2) = arcood(i,2)
            coodma(2,l,1) = arcood(i,1) - j
            coodma(2,l,2) = arcood(i,2) + j
            coodma(3,l,1) = arcood(i,1)
            coodma(3,l,2) = arcood(i,2) + j
            coodma(4,l,1) = arcood(i,1) + j
            coodma(4,l,2) = arcood(i,2) + j
            coodma(5,l,1) = arcood(i,1) + j
            coodma(5,l,2) = arcood(i,2)
            coodma(6,l,1) = arcood(i,1) + j
            coodma(6,l,2) = arcood(i,2) - j
            coodma(7,l,1) = arcood(i,1)
            coodma(7,l,2) = arcood(i,2) - j
            coodma(8,l,1) = arcood(i,1) - j
            coodma(8,l,2) = arcood(i,2) - j
            l = l + 1
460       continue
```

```
c                    NOW CONVERT COORDINATES TO SITES
```

```
c                    MAKING NON-EXISTENT SITES = 0
```

```
      DO 500 i = 1,8
      do 500 j = 1,staaps
         do 400 k = 1,maxsit
            if (coodma(i,j,1).eq.arcood(k,1).and.
     c          coodma(i,j,2).eq.arcood(k,2)) then
                coodma(i,j,1) = k
                coodma(i,j,2) = 0
                go to 450
            end if
400      continue
                coodma(i,j,1) = 0
                coodma(i,j,2) = 0
450   continue
500   continue
```

```
c                  STRIP ZEROS: COUNT SITES / DIRECTION
```

```
      k = 0

      DO 700 i = 1,8
         do 600 j = 1,staaps
            if (coodma(i,j,1).gt.0) then
               k = k + 1
            end if
600      continue
         coodma(i,j,2) = k
700   continue
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                    ASSIGN APPARENT SPECIES TO SITES
```

```
      do 900 i = 1,8
      DO 900 j = coodma(i,1,2),1,-1
      do 900 k = 1,maxlis
          if (ararr(k,1).eq.coodma(i,j,1))then
          do 800 l = i,sitrch
            if (ararr(k,2).eq.sitsit(l))then
            do 750 n = coodma(i,1,2)-1,1,-1
              arappr(maxapp,1) = coodma (i,n,1)
              arappr(maxapp,2) = sitsit(l)
              arappr(maxapp,3) = ararr(k,3)
              maxapp = maxapp + 1
750         continue
            end if
800       continue
          end if
900     continue
```

```
C                    CHECK SIZE OF MATRIX AND REDUCE
```

```
      if (maxapp.gt.imaxap) then
         write (iwrunt,35)arappr(imaxap,1)
         stop
      else if (maxapp.gt.chkapp) then
```

```
C                 REMOVE SPECIES ALREADY PRESENT AT SITES
```

```
         call parity (ararr,arappr,imaxli,imaxap,maxlis,maxapp)
         call strpit (maxapp,arappr,imaxap)
      else
      end if
```

```
C                          RESET CHECKING INTERVAL
```

```
      if (chkapp.gt.imaxap-990) then
         chkapp = maxapp + 500
      else
         chkapp = maxapp + 1000
      end if
1000  continue

      call parity (ararr,arappr,imaxli,imaxap,maxlis,maxapp)
      call strpit (maxapp,arappr,imaxap)
```

```
c                WRITE TO OUTPUT FILE AFTER SELECTING FORMAT
```

```
      if (maxsit.gt.999.or.maxspp.gt.999)then
          forein ='(7(2i4,i3))'
          i = 7
      else if(maxsit.gt.99.or.maxspp.gt.99)then
          forein ='(8(3i3))'
          i = 8
      else
          forein ='(11(2i2,i3))'
          i = 11
      end if

105   format(i4,a74)
      write (iwrout,105)i,forein
      write (iwrout,forein) ((arappr(i,j),  j=1,3), i=1,maxapp)

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine apread (arappr, imaxap, maxapp,maxsit,maxspp,iwrunt)
c               READS IN APPARENT SPECIES TO ARAPPR FROM FILE
c_____________________________________________________________________

c     character*74 FORRIN       !  input format
c     integer  ILINE            !  records per line
c     integer  IMAXAP           !  max size of arappr
c     integer  ARAPPR(IMAXAP,3) !  data array apparent spp
c     integer  MAXAPP, MAXSIT, MAXSPP ! maximum variables
c     integer  IRDAPP,IWRUNT    ! input data set, output file messages

      character*74 FORRIN
      integer  ILINE
      integer  IMAXAP
      integer  ARAPPR(IMAXAP,3)
      integer  MAXAPP, MAXSIT, MAXSPP
      integer  IRDAPP,IWRUNT
      parameter (IRDAPP = 9)

      open(9,file='inappr.doc')

105   format(i4,a74)
205   format(' Site value to high:  incorrect apparent site!')
215   format(' Spp value to high:  incorrect apparent species!')
225   format(' Check that correct matrix has been assigned')
```

```
C                              READ IN DATA
```

```
        read(irdapp,105)iline,forrin

100   continue
        read(irdapp,forrin,iostat=ioerr,err=50,end=50)
     c        (arappr(i,1),arappr(i,2),arappr(i,3),
     c                  i = maxapp, (maxapp+iline-1))
        maxapp=maxapp+iline
50    if (ioerr.eq.0) then
        go to 100
      end if
```

```
C                   CHECK FOR VARIABLES OUT OF RANGE
```

```
      do 200   i = 1,maxapp
      if (arappr(i,1).gt.maxsit) then
       write (iwrunt,205)
       write (iwrunt,225)
      stop
      end if

      if (arappr(i,2).gt.maxspp)then
       write (iwrunt,215)
       write (iwrunt,225)
      stop
      end if

200   continue

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
*************************************************************************
      subroutine chckit(iwrunt,alpha,value)
c            CHECKING IF LIMITS OF COMPILED ARRAYS ARE EXCEEDED:
                  IF SO,  STOP EXECUTION!
c_____________________________________________________________________

c     ALPHA    !  required array size
c     VALUE    !  maximum compiled array size
c     IWRUNT   !  write unit input number

      integer ALPHA
      integer VALUE
      integer IWRUNT

105   format(' Error:  you must recompile the programme.',/, 'It is not
     c capable of dealing with such a large value: ',/,'  you need to
     c  change the relevant parameters at the start of the programme ')

C                                CHECK

      if (alpha.gt.value) then
           write(iwrunt,105)
           stop

      else
      end if

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine endit (iwrunt, ararr, maxlis, imaxli)
c             REPORTS ON SPP STATUS AFTER ALL RESERVES ASSIGNED
C_____________________________________________________________________

      integer maxlis, imaxli,iwrunt
      integer ararr(imaxli,3)

C                                PRINT DUMP

15    format(' Dump of species not yet adequately conserved follows:
     c   ',/)
25    format(' ',12(2i4),' /')
      write (iwrunt,15)
      write (iwrunt,25)((ararr(i,j), j=1,2), i = 1,maxlis)

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine inchit (ararr,imaxli,maxlis,maxspp,maxsit,iwrunt)
c               CHECKS THAT DATA ARE WITHIN SPECIFIED RANGE
C_____________________________________________________________________

      integer ararr (imaxli,3)
      integer maxlis,maxspp,maxsit,iwrunt,imaxli
      logical test

        test = .false.

15    format (' size of input data list  =',i7)
25    format (' site number',i7,' exceeds specifd max for spp:',i7,
     c ' at records ',2i5)
35    format (' species number',i7,' exceeds specifd max for site:',i7,
     c ' at records ',2i5)
45    format (' duplicate species recorded',i7,' for site ',i7,
     c ' at records ',2i5)
55    format (' remove duplicates before proceeding!')
65    format (' remove error before proceeding!')

      write (iwrunt,15) maxlis

c                              CHECK SITES

      do 300 i = 1,maxlis

         if (ararr(i,1).gt.maxsit) then
            write(iwrunt,25)ararr(i,1),ararr(i,2),i
            write(iwrunt,65)
            stop
         end if

C                              CHECK SPECIES

         if (ararr(i,2).gt.maxspp) then
             write(iwrunt,35)ararr(i,2),ararr(i,1),i
            write(iwrunt,65)
             stop
         else
         end if

300   continue

C                       CHECK FOR DUPLICATE RECORDS

      do 200 i = 1,maxlis
      do 200 j = i+1,maxlis
         if (ararr(i,2).gt.0.and.
     c       ararr(i,2).eq.ararr(j,2).and.
     c       ararr(i,1).eq.ararr(j,1)) then
                write(iwrunt,45) ararr(i,2),ararr(i,1),i,j
                test = .true.
         else
         end if

200         continue

C                  STOP PROGRAMME IF DUPLICATES PRESENT

         if (test) then
               write(iwrunt,55)
               stop
         else
         end if

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine parait (iwrunt, irdpar, maxsit, imaxsi, maxspp,
     c      imaxsp, maxlis, imaxli, maxrec, forman, staptr, starpp,
     c      staost, istaos, staopp, istaop, staaps, staapc, maxres,
     c      stapre, stares, istare, stacse, stacrc,
     c      arrost, arropp, arrres, inptt,  strand,
     c      strano, stinhi, stseed, stfirs)
C             READING IN THE PARAMETERS TO RUN THE PROGRAMME
c_____________________________________________________________________

c              ALL VALUES ARE DEFINED IN MAIN PROGRAMME

      INTEGER iwrunt, irdpar, inptt
      INTEGER maxsit, maxspp, maxlis, maxrec, maxres
      INTEGER imaxsi, imaxsp, imaxli, istaos, istaop, istare
      INTEGER staptr, starpp, staost, staopp, staaps, staapc
      INTEGER stapre, stares, stacse, stacrc,strand
      integer strano, stinhi, stseed, stfirs
      INTEGER arrost(istaos), arropp(istaop), arrres(istare)
      CHARACTER*77 forman

15    format(i3,a77)
25    format(' ',i10,/)
35    format(' yes:',i3,/)
45    format('  no:',i3,/)

C                            PARAMETER DATA

105   format('0                PARAMETER DATA:',/)
      Write(iwrunt,105)
115   format(' How many sites are there?')
      Write(iwrunt,115)
      Read(irdpar,*) maxsit
      Write(iwrunt,25) maxsit
         call chckit (iwrunt, maxsit, imaxsi)
125   format(' How many species are there?')
      Write(iwrunt,125)
      Read(irdpar,*) maxspp
      Write(iwrunt,25) maxspp
         call chckit (iwrunt, maxspp, imaxsp)
135   format(' How many records (specimens) in the data set?')
      Write(iwrunt,135)
      Read(irdpar,*) maxlis
      Write(iwrunt,25) maxlis
         call chckit (iwrunt, maxlis, imaxli)
136   format(' How is the data provided: ',/,'   if the list is provided
     c in site, species, value order then type 1',/,'  else if in
     c species, sites,value order then type 2')
      Write(iwrunt,136)
      Read(irdpar,*) inptt
        if (inptt.lt.3.and.inptt.gt.0)then
           Write(iwrunt,25) inptt
        else
           write(iwrunt,*)' invalid format'
        end if
145   format(' What is the maximum number of spp/sites per line input
     c (columns 1-3)',/,' and the format of the data (only integer
     C vals)?',/, ' finish off the input with zero in the site column')
      Write(iwrunt,145)
      Read(irdpar,15) maxrec, forman
      Write(iwrunt,25) maxrec
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
146   format(' Do you wish to check your data for duplicate records
     c  data out of range?',/,'   HIGHLY RECOMMENDED FOR FIRST RUNS',
     C /,  '  Yes = 1; No (default) = 0')
       write (iwrunt,146)
       read(irdpar,*)stfirs
         if (stfirs.eq.1) then
           write(iwrunt,35)stfirs
         else
           stfirs=0
           write(iwrunt,45)stfirs
         end if
```

```
C                              PRINTOUT OPTIONS
```

```
155   format('0                PRINTOUT OPTIONS:',/)
      Write(iwrunt,155)
165   format(' Do you wish to see species number per site after each
     c loop:',/,'  Yes: type 1,  Default = No: type 0')
       Write(iwrunt,165)
       Read(irdpar,*) staptr
         if (staptr.eq.1) then
         Write(iwrunt,35) staptr
         else
           staptr = 0
         Write(iwrunt,45) staptr
         end if

175   format(' Do you wish to see calculations for all existing
     c reserves:',/,'  Yes: type 1,  Default = No: type 0')
       Write(iwrunt,175)
       Read(irdpar,*) starpp
         if (starpp.eq.1) then
           Write(iwrunt,35) starpp
         else
           starpp = 0
           Write(iwrunt,45) starpp
         end if

176    format(' Do you wish to suppress all output except reserve
     c names and spp and populations conserved?',/,'  Yes: type 1,
     c No: type 0')
        write (iwrunt,176)
        read(irdpar,*) stinhi
          if (stinhi.eq.1) then
           write(iwrunt,35)stinhi
          else
           stinhi = 0
           write(iwrunt,45)stinhi
          end if
```

```
C                     DATA MODIFICATION:  DELETIONS
```

```
185   format('0                DATA MODIFICATION:  DELETIONS:',/)
      Write(iwrunt,185)
195   format(' Do you wish to omit any sites?  If so,  record the numbe
     cr of sites',/,' and on the next line provide sites in I4 format
     c (maximum 20 per line).',/,'  If no merely type 0 on one line')
       Write(iwrunt,195)
       Read(irdpar,*) staost
       Write(iwrunt,25) staost
          call chckit (iwrunt, staost, istaos)
          if (staost.gt.0) call rondit(irdpar, staost, arrost, istaos)
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
205    format(' Do you wish to omit any species? If so, record number of
     c species and',/,' on the next line provide sites in I4 format
     c (maximum 20 / line).',/,'  If no merely type 0 on one line')
       Write(iwrunt,205)
       Read(irdpar,*) staopp
       Write(iwrunt,25) staopp
          call chckit (iwrunt, staopp, istaop)
         if (staopp.gt.0) call rondit (irdpar, staopp, arropp, istaop)
```

```
C              DATA MODIFICATION OPTIONS: APPARENT SPECIES
```

```
215    format('0      DATA MODIFICATION OPTIONS: APPARENT SPECIES:',/)
       Write(iwrunt,215)
225    format(' Do you wish to use apparent species to select reserves?
     c  ',/,' If Yes: type the number of linear squares over which
     c apparent species must be assigned.',/,'  Apparent species are
     c only assigned after unwanted sites and spp are removed. ',/,
     c ' A file called inappr.doc must be available for collecting the
     c list of apparent species:',/,'  if you wish to use this file in
     c future make sure that no sites or species are omitted in your
     c first run',/,
     c ' In subsequent runs type 99 to use the data in file inappr.doc:'
     c,/,  ' unwanted species and sites are removed later as required'
     c ,/,' Default = No: type 0')
       Write(iwrunt,225)
       Read(irdpar,*) staaps
       Write(iwrunt,25) staaps
          if (staaps.gt.0) write(iwrunt,235)
235    format(' Put your coordinate data (as degrees + minutes, with
     c decimals of minutes), into file IRDC.DOC ',/,' The first line
     c must contain the data format: [site,4 X coord (o'',o''):',/,
     c ' e.g.,6(i2,2(f2.0,f3.1)) ] with the number of coordinates per
     c line in columns 1-3',/,' and the interval between adjacent grid
     c units in columns 4-8.')
245    format(' Do you wish to consider apparent species conserved?:
     c ',/,' Yes: type 1,  Default = No: type 0')
       Write(iwrunt,245)
       Read(irdpar,*) staapc
       Write(iwrunt,25) staapc
```

```
C                          RESERVE OPTIONS
```

```
255    format('0                RESERVE OPTIONS',/)
       Write(iwrunt,255)
265    format(' What is the maximum number of reserves to be created?
     c For default (=number of sites) type 0')
       Write(iwrunt,265)
       Read(irdpar,*) maxres
       Write(iwrunt,25) maxres
         if (maxres.eq.0) maxres = maxsit
275    format(' In how many reserves must each species be preserved?')
       Write(iwrunt,275)
       Read(irdpar,*) stapre
        if (stapre.le.0)then
          stop
        else
          Write(iwrunt,25) stapre
        end if
285    format(' How many reserves already exist?  If any,  record the
     c number of sites',/,'  and on the next line provide sites in I4
     c format (maximum 20 per line,in sequence). ',/,' If no merely
     c type 0 on one line')
       Write(iwrunt,285)
       Read(irdpar,*) stares
       Write(iwrunt,25) stares
          call chckit (iwrunt, stares, istare)
         if (stares.gt.0)  call rondit (irdpar, stares, arrres,istare)
286    format(' Preselected (existing) reserves =',/,30(20i6,/))
       if (stares.gt.0)  write(iwrunt,286) (arrres(i),i=1,stares)
```

```
        1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                        RESERVE SELECTION OPTIONS
```

```
295    format('0                RESERVE SELECTION OPTIONS',/)
       Write(iwrunt,295)
305    format(' What algorithm would you like to use to select sites
     c as reserves?  options are:')
315    format('  1. Species richness only',/,
     c '  2. Species richness of unconserved species only',/,
     c '  3. Species richness of unconserved real+app species',/,
     c '  4. Remaining unique species only',/,
     c '  5. Weighted by sum of values provided',/,
     c '  0 = Default - Weighted by sum of values, ',/,' where value
     c for species =   1 / abundance (i.e. 1/# sites present) ')
       Write(iwrunt,305)
       Write(iwrunt,315)
       Read(irdpar,*) stacse
       Write(iwrunt,25) stacse
325    format(' What algorithm would you like to use to resolve
     c conflicts in selecting sites as reserves?')
       Write(iwrunt,325)
       Write(iwrunt,315)
       Read(irdpar,*) stacrc
       Write(iwrunt,25) stacrc
```

```
c           RANDOM SELECTION OF RESERVES AS NULL HYPOTHESIS
```

```
330      format(' Do you wish to select reserves at random?',/,
     c ' if no,  then type 0',/,
     c ' if yes, then type in the number of reserves; ',/,
     c '  followed by a seed number (positive uneven about 5 digits)
     c for the random number generator on the next line')
         write (iwrunt,330)
         read (irdpar,*) strano
       if (strano.eq.0) then
          strand = 0
          stseed = 0
       else
          strand = 1
          read (irdpar,*) stseed
       end if
         write (iwrunt,25)strano
         write (iwrunt,25)stseed

       return
       end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**************************************************************************
      subroutine parity (ararr,arappr,imaxli,imaxap,maxlis,maxapp)
c               REMOVES SPP FROM ARAPPR SITES ALREADY IN ARARR
c_____________________________________________________________________

C     integer IMAXAP, IMAXLI   !   maximum array sizes
C     integer MAXAPP, MAXLIS   !   current array sizes
C     integer ARARR(IMAXLI,3)    !   data array
C     integer ARAPPR(IMAXAP,3)   !   apparent spp array

      integer IMAXAP, IMAXLI
      integer MAXAPP, MAXLIS
      integer ARARR(IMAXLI,3)
      integer ARAPPR(IMAXAP,3)

C                    TAKE OUT DUPLICATE SITES/SPP

      do 100 i = 1,maxapp
      do 100 j = i+1,maxapp
         if (arappr(i,1).eq.arappr(j,1).and.
     c        arappr(i,2).eq.arappr(j,2)) then
              arappr(j,1) = 0
              arappr(j,2) = 0
         end if
100   continue

C                    TAKE OUT SPECIES ALREADY PRESENT

      do 200 i = 1,maxapp
      do 200 j = 1,maxlis
         if (arappr(i,1).eq.ararr(j,1).and.
     c        arappr(i,2).eq.ararr(j,2)) then
              arappr(i,1) = 0
              arappr(i,2) = 0
         end if
200   continue

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine prntit (iwrunt, arspp, maxspp, imaxsp,stinhi)
c                THIS IS THE STEP BY STEP PRINTING ROUTINE
c_____________________________________________________________________

c     integer ARSPP(maxspp,2)  !  array: tot occur;  num reserve/spp
c     integer MAXSPP           !  size of arspp
c     integer IWRUNT           !  write unit input number
c     integer IMAX             !  printer counter
c     integer IMAX1            !  printer counter
c     integer STINHI           !  inhibit printout

      integer ARSPP(imaxsp,2)
      integer MAXSPP
      integer IWRUNT
      integer IMAX,IMAX1
      integer STINHI

115   format (' species number ',25i4)
125   format (' totl occurrencs',25i4)
135   format (' number reserves',25i4,/)
145   format ('  ',/,' sum of species  conserved is: 'i5,'  in',i6,
     c          '  populations',//)

c                                PRINT

      if (stinhi.eq.0) then

      do 100 i = 1,maxspp,25

         if (i+24.gt.maxspp) then
           imax = maxspp
         else
           imax = i+24
         end if

         write(iwrunt,115) (j,  j = i,imax)
         write(iwrunt,125) (arspp(j,1), j = i,imax)
         write(iwrunt,135) (arspp(j,2), j = i,imax)

100   continue

      else
      end if

c                        SUM UP CONSERVATION TOTALS

      imax=0
      imax1=0

      do 200 i=1,maxspp
        imax = imax + arspp(i,2)
        if (arspp(i,2).gt.0)then
           imax1 = imax1 + 1
        end if
200   continue

      write (iwrunt,145) imax1,imax

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine qukrem
     c  (iwrunt, ararr, maxlis, arrres, stares, arspp, maxspp,
     c  imaxli, istare, imaxsp, imaxal, maxalt, aralt, stapre,numres,
     c  stinhi)
c              REMOVING RESERVES WHEN NO REPORT BACK REQUIRED
c_____________________________________________________________________

c      integer ARARR(maxlis,3)  !  data matrix
c      integer ARRRES(stares)   !  reserve numbers
c      integer STARES           !  number of reserves
c      integer MAXLIS           !  number of specimens
c      integer ARSPP(maxspp,2)  !  # reserves for each species
c      integer MAXSPP           !  number of species
c      integer ARALT(maxalt,3)  !  array for adequately conserved spp
c      integer STAPRE           !  number of reserves required per spp
c      integer STINHI           !  no output set to zero
c      integer STNAME           !  temp variable for reserve used/iteratn
c      integer IXXX             !  dummy variable for stinhi

       integer IMAXLI, ISTARE, IMAXSP, IMAXAL, MAXALT, IWRUNT
       integer ARARR(imaxli,3)
       integer ARALT(imaxal,3)
       integer ARSPP(imaxsp,2)
       integer ARRRES(istare)
       integer MAXLIS, MAXSPP
       integer NUMRES
       integer STARES
       integer STNAME
       integer STINHI
       integer STAPRE
       integer IXXX

15     format('1 removing reserve no ',i5,'  as site no ',i5,/)
45     format('  removing reserve no ',i5,'  as site no ',i5,/)
25     format(' ',/,' existing reserves removed: data dump follows')
35     format(10(' ',2i5,'/'))
```

```
c                          REMOVE CONSERVED SITES
```

```
       do 200 j = 1,stares

          stname = arrres(j)

           if (stinhi.eq.0) then
             write(iwrunt,15) j, stname
           else
             write(iwrunt,45) j, stname
           end if

          call talyit (imaxli, maxlis, ararr, imaxsp, maxspp,
     c      imaxal, maxalt, aralt, arspp, stname, stapre, iwrunt)
```

```
c                          STRIP OFF UNWANTED LENGTH
```

```
          call strpit (maxlis, ararr, IMAXLI)
          call strpit (maxalt, aralt, IMAXAL)

          numres = numres + 1
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                    PRODUCE A PRINTOUT OF STATUS
```

```
          ixxx = stinhi
          stinhi = 1
         call prntit (iwrunt, arspp, maxspp, imaxsp,stinhi)
          stinhi = ixxx

200     continue

        write(iwrunt,25)
        write(iwrunt,35)(ararr(i,1),ararr(i,2), i = 1,maxlis)

        return
        end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
        subroutine   random
     c    (arsun,imaxsi,maxsit,arrres,istare,stares,stseed,strano)
c                          ASSIGN RANDOM RESERVES
c_____________________________________________________________________

c       integer arsun   ! number of initial species (maxsit)
c       integer arrres  ! reserve numbers (stares)
c       integer stseed  ! seed number for random number gen
c       integer strano  ! no of reserves to be randomly allocated
c       integer summit  ! sum of existing reserves and random reserves
c       real r          ! variable for random interval (0 - 1)
c       real select     ! variable for interval (1,maxsit)
c       integer select1 ! integer of select variable for interval (1,maxsit)

        integer arsun(imaxsi,4),  arrres(istare)
        integer maxsit,stares,stseed,strano,select1,summit
        real r, select

        summit = stares

100     if (summit.lt.strano+stares) then

c                    OBTAIN SEED = CONVERT TO RESERVE

           r = ran (stseed)
           select = r * maxsit
           select1 = select

C                              DISCARD IF ZERO

           if (select1.eq.0) go to 100

C                        DISCARD IF ALREADY ASSIGNED

           do 200 i = 1,summit
             if (arrres(i).eq.select1) go to 100
200        continue

C                    DISCARD IF LESS THAN 2 SPECIES

           if (arsun(select1,1).le.2) then
           else

c                    IF ABOVE OK TRANSFER TO ARRRES

              summit = summit +1
              arrres(summit) = select1
           end if
           go to 100

        else
        end if

         stares = summit
         return
         end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine readit (irddat,maxrec, ararr, maxlis,forman,imaxli,
     c                   ival)
C                           READ IN RAW DATA
c_____________________________________________________________________

c       character*77  FORMAN       !  input format
c       integer ARARR(IMAXLI,3)    !  data array
c       integer IRDDAT             ! read unit input number
c       integer MAXREC             !  size of input array
c       integer MAXLIS             !  size of data array
c       integer SITE               !  site input
c       integer SPECIE(50)         !  species input array
c       integer VALUE(50)          !  value input array (eg rarity status)

      character*77  FORMAN
      integer MAXLIS
      integer SITE
      integer SPECIE (50)
      integer VALUE (50)
      integer ARARR(IMAXLI,3)
      integer IRDAT
      integer MAXREC

      open(17,file='raster.data')
      irdat=17
```

```
c                          SET VARIABLES TO 0
```

```
      data specie /50*0/
      data value /50*0/
      site = 0
      J = 1
      if (ival.eq.1)then
```

```
C          READ IN ALL THE DATA INTO ARARR( SITE,SPECIE,VAL)
```

```
      read(irdat,forman) site,(specie(i),value(i), i = 1,maxrec)

300      do 400 i = 1,maxrec
         if (specie(i).ne.0) then
            ararr(j,1) = site
            ararr(j,2) = specie(i)
            ararr(j,3) = value(i)
            j = j + 1
         else
         end if
400   continue
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                          READ NEXT & REPEAT
```

```
c              STOP IF THE FIRST VALUE IN THE LINE IS ZERO
```

```
      read(irdat,forman,iostat=ioerr,err=50,end=50)
     c                  site,(specie(i),value(i),  i = 1,maxrec)
50    if (ioerr.eq.0) then
         if (site.ne.0)then
         go to 300
      end if
      else
      site=0
      end if

           maxlis = j-1

      else if(ival.eq.2)then
```

```
C           READ IN ALL THE DATA INTO ARARR(SPECIE,SITE,VAL)
c                NOW 'SPECIE' = SITES AND 'SITE' = SPP
```

```
      read(irdat,forman) site,(specie(i),value(i), i = 1,maxrec)

1300       do 1400 i = 1,maxrec
         if (specie(i).ne.0) then
            ararr(j,1) = specie(i)
            ararr(j,2) = site
            ararr(j,3) = value(i)
            j = j + 1
         else
         end if
1400    continue
```

```
c                          READ NEXT & REPEAT
c              STOP IF THE FIRST VALUE IN THE LINE IS ZERO
```

```
      read(irdat,forman,iostat=ioerr,err=1150,end=1150)
     c                  site,(specie(i),value(i),  i = 1,maxrec)
1150     if (ioerr.eq.0) then
            if (site.ne.0)then
            go to 1300
         end if
      else
         site=0
      end if

           maxlis = j-1

      end if

500   return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine rondit (irdpar, arrlim, array, ilim)
C                 READING SITES AND SQUARES TO BE LEFT OUT
c_____________________________________________________________________

C     integer ARRLIM              ! size of array
C     integer ARRAY(arrlim)       ! input array
C     integer IRDPAR              ! read unit input number
C     integer VALUE               ! iteration variable
C     real    SQUARE              ! alt iteration variable

      integer ARRLIM
      integer ARRAY(ilim)
      integer IRDPAR, ILIM
      integer VALUE
      real    SQUARE

15    format(20i4)
```

```
c                          CALCULATE LINES OF INPUT
```

```
        square = arrlim
        if (square/20..gt.arrlim/20)then
           value = arrlim/20 + 1
        else
           value = arrlim/20
        end if
```

```
C                                  READ DATA
```

```
      j = 1
      do 100 i = 1,value
         read(irdpar,15)(array(j),  j = j,(j + 19))
100   continue

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**************************************************************************
      subroutine slctit (iwrunt, stacse, stname, imaxco, maxsit,
     c                   imaxsi, val, arsun, arsit)
C                        SELECTING SITES FOR RESERVES
c_____________________________________________________________________

C       integer IWRUNT           !  write unit
C       integer STACSE           !  choice of selection
C       integer STNAME           !  site with highest conservation value
C       integer MAXSIT           !  maximum number of sites
C       integer IMAXSI           !  size of site data arrays
C       integer VAL              !  value for selecting array elements
C       integer ARSUN(imaxsi,4)  !  original summary per site
C       integer ARSIT(imaxsi,4)  !  current summary per site

C       integer ARSTA(2500)      !  value for selecting reserves
C       integer CONFLT(500,2)    !  site value :  dump for conflt sites
C       integer MAXCON           !  maximum number of conflict sites
C       integer IA(2)            !  sort variable for array conflt

        integer IWRUNT
        integer STACSE
        integer STNAME
        integer MAXCON
        integer MAXSIT
        integer IMAXSI
        integer VAL
        integer ARSTA(2500)
        integer ARSUN(imaxsi,4)
        integer ARSIT(imaxsi,4)
        integer CONFLT(500,2)
        integer IA(2)
```

```
C                                INITIALIZE
```

```
        do 100 i=1,imaxco
          conflt(i,1) = 0
          conflt(i,2) = 0
100     continue

        DO 200 i=1,maxsit
          arsta(i) = 0
200     continue

         stname = 1
```

```
C                          INPUT CHOICE FOR SELECTION
```

```
        If (stacse.eq.1) then
             do 1200 i = 1,maxsit
              arsta(i) = arsun(i,1)
1200         continue
        else If (stacse.eq.2) then
             do 1300 i = 1,maxsit
              arsta(i) = arsit(i,1)
1300         continue
        else If (stacse.eq.3) then
             do 1400 i = 1,maxsit
              arsta(i) = arsit(i,1) + arsit(i,2)
1400         continue
        else If (stacse.eq.4) then
             do 1500 i = 1,maxsit
              arsta(i) = arsit(i,3)
1500         continue
        else If (stacse.eq.5.or.stacse.eq.0) then
             do 1600 i = 1,maxsit
              arsta(i) = arsit(i,4)
1600         continue
        else
        end if
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                    DETERMINE THE PRIORITY SITE
```

```
      do 1700 i = 1,maxsit
        if (arsta(i).ge.arsta(stname)) then
           stname = i
        else
        end if
1700  continue
```

```
C            CHECK OPTION CONFLICTS (yes: set maxcon to >1
```

```
      maxcon = 0
      do 1800 i = 1,maxsit
        if (arsta(i).ge.arsta(stname)) then
          maxcon = maxcon + 1
          conflt(maxcon,1) = i
        else
        end if
1800  continue

      if (maxcon.gt.1) then
```

```
C              RESOLVE CONFLICT USING CONFLICT OPTION
```

```
345       format (' option conflict on choosing sites:',
     c             2014,/,' ',5(3014,/,' '))
          write(iwrunt,345) (conflt(i,1), i = 1,maxcon)
             If (stacrc.eq.1) then
                  do 1900 i = 1,maxcon
                   conflt(i,2) = arsun(conflt(i,1),1)
1900              continue
             else If (stacrc.eq.2) then
                  do 2000 i = 1,maxcon
                   conflt(i,2) = arsit(conflt(i,1),1)
2000              continue
             else If (stacrc.eq.3) then
                  do 2100 i = 1,maxcon
                      conflt(i,2) = arsit(conflt(i,1),1)
     c                              + arsit(conflt(i,1),2)
2100              continue
             else If (stacrc.eq.4) then
                  do 2200 i = 1,maxcon
                   conflt(i,2) = arsit(conflt(i,1),3)
2200              continue
             else If (stacrc.eq.5.or.stacrc.eq.0) then
                  do 2300 i = 1,maxcon
                   conflt(i,2) = arsit(conflt(i,1),4)
2300              continue
             else
             end if
      else
      end if
```

```
c            TEMPORARILY DESIGNATE STNAME AS A VAR OF CONFLT
```

```
       stname = 1
```

```
C                    DETERMINE THE 2ry PRIORITY SITE
```

```
      do 2400 i = 1,maxcon
        if (conflt(i,2).ge.conflt(stname,2)) then
           stname = i
        else
        end if
2400  continue
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                    CHECK IF CONFLICTS RESOLVED
```

```
      val = 0
      do 2500 i = 1,maxcon
        if (conflt(i,2).ge.conflt(stname,2)) then
          val  =  val  +  1
          conflt(i,2) = arsun(conflt(i,1),4)
        else
          conflt(i,1) = 0
          conflt(i,2) = 0
        end if
2500  continue
```

```
c         IF NOT RESOLVED (v>1), RESOLVE WITH ABUNDANCE VALUES
```

```
      if (val.gt.1) then
          stname = 1

          do 2650 i = 1, maxcon
          do 2650 j = i+1, maxcon
             if (conflt(i,2).lt.conflt(j,2))then
                do 2670 k = 1,2
                    ia(k) = conflt(j,k)
                    conflt(j,k) = conflt(i,k)
                    conflt(i,k) = ia(k)
2670            continue
             else
             end if
2650         continue

355       format (' option conflict on choosing sites not resolved:',
     c /,' site',I4,'  chosen by weighted abundance as containing
     c  most rares out of sites (in < order): ')
375       format (25i5)
             write(iwrunt,355) conflt(stname,1)
             write(iwrunt,375) (conflt(i,1), i=1,val)
      val=0

      else
385       format('  resolved:  site ',i4,' chosen')
             write(iwrunt,385)conflt(stname,1)
      end if
```

```
c                    REASSIGN STNAME ITS CORRECT VALUE
```

```
          stname = conflt(stname,1)
      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**************************************************************************
      subroutine sireit
     c         (maxarr, array, value, maxlis, ararr, imaxli, illum)
C                        REMOVAL OF UNWANTED UNITS
c_____________________________________________________________________

c       integer MAXARR             !   size of array
c       integer MAXLIS             !   actual size of ararr
c       integer ARRAY(maxarr)      !   array with variables
c       integer ARARR(imaxli,3)    !   data array
c       integer VALUE              !   dimension variable

        integer MAXARR
        integer MAXLIS
        integer ARRAY(illum)
        integer ARARR(imaxli,3)
        integer VALUE
```

```
C                    REMOVE SITES LISTED AS UNWANTED
```

```
        do 100 i = 1,maxarr
           do 100 j = 1,maxlis
              if(ararr(j,value).eq.array(i)) then
                 ararr(j,1) =  0
                 ararr(j,2) =  0
                 ararr(j,3) =  0
              else
              end if
100        continue

        return
        end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**************************************************************************
      subroutine sortit
     c          (val, arsss, arrrar, maxszz, maxstt, maxmax, imaxsi)
c                     SUMMATION OF VALUES FOR EACH SITE
c_____________________________________________________________________

c      integer ARSSS (imaxsi,4)  !   size of summation array
c      integer ARRRAR(maxmax,3)  !   data array
c      integer VAL               !   dimension value for arsss
c      integer MAXMAX            !   maximum limits of arrrar
c      integer MAXSTT            !   size of arsss
c      integer MAXSZZ            !   size of arrarr

       integer ARSSS (imaxsi,4)
       integer ARRRAR(maxmax,3)
       integer VAL
       integer MAXMAX
       integer MAXSTT
       integer MAXSZZ

c                     RESET RELEVANT COLUMN TO ZERO

       do 100 i=1,maxstt
         arsss(i,val)=0
100    continue

c                   DETERMINE AND ASSIGN SPP RICHNESS

       do 200 j = 1,maxstt
       do 200 i = 1,maxszz
          if (arrrar(i,1).eq.j) then
             arsss(j,val) = arsss(j,val) + 1
          else
          end if
200    continue

       return
       end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**************************************************************************
      subroutine statit(iwrunt, staaps, arsit, arsun, maxsit, imaxsi)
C                       INTERMEDIATE PRINTOUT ROUTINE
c_____________________________________________________________________

c     APP,ITE,REM,SPP,TOT,UNI,VAL,ZIL  ! output characters
c     integer ARSIT(maxsit,4)          !  updated statistics
c     integer ARSUN(maxsit,4)          !  original statistics
c     integer MAXSIT                   !  size of arrays
c     integer STAAPS                   !  option for apparent spp
c     integer NUMB(25)                 !  dummy array
c     integer IWRUNT                   !  write unit input number
c     integer imaxi                    !  printout regulator value

      character*4 APP,ITE,REM,SPP,TOT,UNI,VAL,ZIL
      integer ARSIT(imaxsi,4)
      integer ARSUN(imaxsi,4)
      integer MAXSIT
      integer STAAPS
      integer NUMB(25)
      integer IWRUNT
      integer imaxi

C                               INITIALIZE

      app = ' app'
      spp = ' spp'
      uni = ' uni'
      rem = ' rem'
      zil = '    '
      ite = ' sit'
      tot = ' tot'
      val = ' val'

105   format (3a4,25i4)
115   format (' ------------------------------------------------------
     c ------------------------------------------------------------')

      do 300 i = 1,maxsit,25

         if(i+24.gt.maxsit)then
            imaxi =  maxsit
         else
            imaxi = i + 24
         end if
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                                   WRITE
```

```
          write(iwrunt,105) ite,zil,zil,(j,  j = i,imaxi)
          write(iwrunt,115)
          write(iwrunt,105) tot,spp,zil,(arsun(j,1), j = i,imaxi)
            if (staaps.gt.0) then
                write(iwrunt,105)tot,app,spp,(arsun(j,2), j = i,imaxi)
                do 100 j = i,imaxi
                   numb(j)  = arsun(j,1) + arsun(j,2)
100               continue
                write(iwrunt,105) tot,tot,spp,(numb(j), j = i,imaxi)
            else
            end if
          write(iwrunt,105) tot,uni,spp,(arsun(j,3), j = i,imaxi)
          write(iwrunt,105) val,zil,zil,(arsun(j,4)/100, j = i,imaxi)
          write(iwrunt,115)

          write(iwrunt,105) rem,spp,zil,(arsit(j,1), j = i,imaxi)
            if (staaps.gt.0) then
                write(iwrunt,105)rem,app,spp,(arsit(j,2), j = i,imaxi)
                do 200 j = i,imaxi
                   numb(j)  = arsit(j,1) + arsit(j,2)
200               continue
                write(iwrunt,105) tot,rem,spp, (numb(j), j = i,imaxi)
            else
            end if
          write(iwrunt,105) rem,uni,spp,(arsit(j,3), j = i,imaxi)
          write(iwrunt,105) rem,val,zil, (arsit(j,4)/100, j = i,imaxi)

          write(iwrunt,'(/)')
300     continue


        return
        end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine strpit (maxarr, array, maxlim)
c                REMOVING ZEROS AND SHORTENING DATA ARRAYS
c_____________________________________________________________________

c     integer ARRAY(maxlim,3)  !  data array for removing zeros
c     integer ARTEMP (3)       !  flip variable for sorting maxima
c     integer MAXARR           !  current maximum size of data in array
c     integer MAXLIM           !  maximum limits of incoming array
c     integer MAXTEM           !  temp var to update array size

      integer ARRAY(maxlim,3)
      integer ARTEMP(3)
      integer MAXARR
      integer MAXLIM
      integer MAXTEM

      data artemp /3*0/
      maxtem =  0
```

```
c                        CHECK IF SUBROUTINE NEEDED
C                              IF NOT JUMP OUT
```

```
      if (maxarr.lt.1) go to 950
```

```
c                               SORT ARRAY
```

```
      do 800 i = 1,maxarr
        if (array(i,1).le.0) then
        do 750 j = maxarr,  i + 1,  -1
            if (array(j,1).gt.0)then
                do 700 k = 1,3
                   artemp(k) = array(i,k)
                   array(i,k) =  array(j,k)
                   array(j,k) =  artemp(k)
700             continue
                go to 760
            else
            end if
750     continue
760     continue
         else
         end if
800   continue
```

```
c                          DECLARE LIMITS OF ARRAY
```

```
      maxtem = 1
900     if (array(maxtem,1).gt.0) then
           maxtem = maxtem + 1
           go to 900
        else
        end if
      maxarr = maxtem - 1

950   continue
      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
*************************************************************************
      subroutine talyit (imaxli, maxlis, ararr, imaxsp, maxspp,
     c           imaxal, maxalt, aralt, arspp, stname, stapre,iwrunt)
C                    TALLYING UP CONSERVED SPECIES,
C                  AND SORTING ADEQUATELY CONSERVED SPP
c_____________________________________________________________________

C      integer MAXLIS            ! size of ararr
C      integer MAXSPP            ! size of arspp
C      integer ARARR (imaxli,3)  ! data array
C      integer ARSPP (imaxsp,2)  ! summary by sites
C      integer STNAME            ! site with highest conservation value
C      integer STAPRE            ! minimum # reserves required per spp
C      integer MAXALT            ! size of aralt
C      integer ARALT (imaxal,3)  ! array containing adequately conserved spp

       integer MAXLIS
       integer MAXSPP
       integer MAXALT
       integer ARARR (imaxli,3)
       integer ARSPP (imaxsp,2)
       integer ARALT (imaxal,3)
       integer STNAME
       integer STAPRE
```

```
c                          REMOVE THIS SITE
```

```
       do 2800 i = 1,maxlis
         if (ararr(i,1).eq.stname) then
           arspp(ararr(i,2),2) = arspp(ararr(i,2),2) + 1
           ararr(i,1) =  0
           ararr(i,2) =  0
           ararr(i,3) =  0
         else
         end if
2800   continue
```

```
c                    TALLY UP ADEQUATELY CONSERVED SPP
```

```
       if (maxalt.gt.0) then
         do 2900 i = 1,maxalt
           if (aralt(i,1).eq.stname) then
             arspp(aralt(i,2),2) = arspp(aralt(i,2),2) + 1
             aralt(i,1) =  0
             aralt(i,2) =  0
             aralt(i,3) =  0
           else
           end if
2900     continue
       else
       end if
```

```
        1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
c                    REMOVE ADEQUATELY CONSERVED SPP
```

```
      do 3200 i = 1,maxspp
        if (arspp(i,2).eq.stapre) then
          do 3100 j = 1,maxlis
             if (ararr(j,2).eq.i) then
                maxalt = maxalt + 1
                do 3000 k = 1,3
                aralt(maxalt,k) =  ararr(j,k)
                   ararr(j,k) = 0
3000            continue
             else
             end if
3100        continue

          end if
3200    continue

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine uniqit
     c         (val,ararr,maxlis,array,maxsit,maxspp, imaxli,imaxsi)
C                          FIXING UNIQUE SPECIES
c_____________________________________________________________________

c     integer VAL              !  2nd dimension in summary array
c     integer ARARR(IMAXLI,3)  !  data array
c     integer ARRAY(IMAXSI,4)  !  summary array
c     integer MAXLIS           !  current size of ararr
c     integer MAXSIT           !  size of array

      integer VAL
      integer ARARR(IMAXLI,3)
      integer ARRAY(IMAXSI,4)
      integer MAXLIS
      integer MAXSIT

      do 20 i = 1,maxsit
        array(i,val) = 0
20    continue

c                          CALCULATE UNIQUE SPECIES

      do 400 i = 1,maxspp
      do 200 j = 1,maxlis

c                               TAKE A SPECIES

         if (i.eq.ararr(j,2))then
            do 100 k = j+1,maxlis

c                           GO OUT IF NOT UNIQUE

              if(ararr(j,2).eq.ararr(k,2)) then
                 go to 300
              else
              end if
100           continue

C                           IF UNIQUE INCREMENT
C                           AND LEAVE LOOP 200

            array(ararr(j,1),val) = array(ararr(j,1),val) + 1
            go to 300
         else
         end if
200   continue
300     continue
400   continue

      return
      end
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
**********************************************************************
      subroutine valuit (val, arstt, ararr,
     c         maxsze, maxste, stacse, maxspz, imaxsp, imaxli, imaxsi)
c                  ASSIGNS PRIORITY VALUES FOR SELECTION
c_____________________________________________________________________

c       integer ARNOSP(MAXSPZ)    !   computed species scores
c       integer ARSTT (IMAXSI,4)  !   size of summation array
c       integer ARARR(IMAXLI,3)   !   data array
c       integer VAL               !   dimension value for arsss
c       integer MAXSPZ            !   max number of species
c       integer MAXSTE            !   size of arstt
c       integer MAXSZE            !   size of ararr
c       integer STACSE            !   option variable for choosing site

        integer MAXSPZ
        integer ARNOSP(2500)
        integer ARSTT(IMAXSI,4)
        integer ARARR(IMAXLI,3)
        integer VAL
        integer MAXSTE
        integer MAXSZE
        integer STACSE
```

```
c                              INITIALIZE
```

```
        do 50 l = 1,2000
            arnosp(l) = 0
50      continue

        do 100 k = 1,maxste
            arstt(k,val) = 0
100     continue
```

```
c               ASSIGN VALUES TO ARSTT DEPENDING ON OPTIONS
```

```
        If (stacse.eq.5) then
```

```
c                   ASSIGN VALUES BASED ON PROVIDED VALUES
```

```
            do 200 m = 1,maxsze
               arstt(ararr(m,1),val) = arstt(ararr(m,1),val)
     c                                  +  ararr(m,3)
200         continue

        else
```

```
c                      TALLY UP NO SITES PER SPECIES
```

```
          do 300 i = 1,maxsze
            arnosp(ararr(i,2)) = arnosp(ararr(i,2)) + 1
300       continue
```

```
C                   DIVIDE NO SITES BY VALUE PER SPP
c                  MULTIPLY BY 100 NOT TO LOOSE FRACTION
```

```
          do 400 j = 1,maxspz
            if (arnosp(j).gt.0) then
              arnosp(j) = 100.*(maxste/arnosp(j))
            end if
400       continue
```

```
      1         2         3         4         5         6         7
1234567890123456789012345678901234567890123456789012345678901234567890123456789012
```

```
C                          COPY SUM INTO ARSTT
```

```
          do 500 n = 1,maxsze
                arstt(ararr(n,1),val) = arstt(ararr(n,1),val)  +
     c                                  arnosp(ararr(n,2))
500       continue
        end if

        return
        end
```

The End